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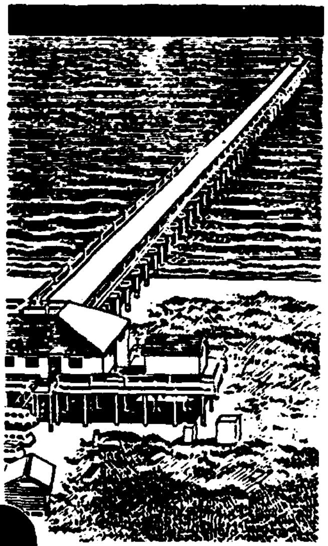
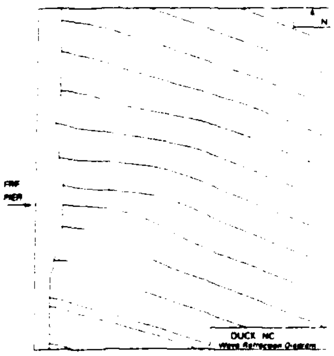
US Army Corps of Engineers

COASTAL MODELING SYSTEM (CMS) USER'S MANUAL





by

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13. ABSTRACT *(Maximum 200 words)*

The Coastal Modeling System (CMS) is a software package aimed at organizing the Coastal Engineering Research Center's larger numerical models and their supporting software into a user-friendly system that is available to all Corps elements having a need to apply the supported modeling technology. Since some of the models share similar input requirements, output capability, and procedural implementation, efforts are made to standardize these portions of the models as much as possible. FORTRAN 77 programming language is used exclusively in the system software to ensure portability of the models and supporting programs to other computer systems. Graphics programs also make use of DISSPLAU~software. Models selected for inclusion in CMS are well advanced in their development and have been rigorously tested over a wide range of conditions. The models in CMS can be considered tested, reliable, and mature. The numerical models documented here include: SPH, WIFM,
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RCPWAVE, CLHYD, and SHALWV. Numerical model SPH is a parametric model for representing wind and atmospheric pressure fields generated by hurricanes. Numerical model WIFM solves the vertically integrated Navier-Stokes equations in stretched Cartesian coordinates. The model simulates shallow-water, long-wave hydrodynamics such as tidal circulation, storm surges, and tsunami propagation. Numerical model RCPWAVE is a short-wave model used to predict linear, plane wave propagation over an open coast region of arbitrary bathymetry. Numerical model CLHYD simulates shallow-water, long-wave hydrodynamics such as tidal circulation and storm surge propagation. CLHYD can simulate flow fields induced by wind fields, river inflows/outflows, and tidal forcing. Numerical model SHALWV is a time-dependent spectral wind-wave model for computing a time-history of wind-generated waves.

linear, plane wave propagation over an open coast region of arbitrary

PREFACE

This manual presents the documentation for several numerical models and supporting software that comprise the Coastal Modeling System. The system development documented here was authorized as part of the Civil Works Research and Development Program of Headquarters, US Army Chief of Engineers (HQUSACE). This work was funded under Work Unit 31675, "Development of a Coastal Modeling System," which is part of the Harbor Entrances and Coastal Channels Program. Messrs. John H. Lockhart, Jr.; John G. Housley; James E. Crews; and Robert H. Campbell were the HQUSACE Technical Monitors.

The system development was conducted under the direction of Dr. James R. Houston, Chief, Coastal Engineering Research Center (CERC) of the US Army Engineer Waterways Experiment Station (WES); Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC; Mr. H. Lee Butler, Chief, Research Division (RD); and Mr. Bruce A. Ebersole, Chief, Coastal Processes Branch (CPB). Technical Editor for the *Coastal Modeling System User's Manual* was Ms. Mary A. Cialone, Research Hydraulic Engineer, CPB, RD. Valuable input was provided by Messrs. Ebersole, Jack E. Davis, David J. Mark, and David A. Leenknecht; Dr. Robert E. Jensen; and Mses. Lucia W. Chou and Dawn E. Abbe. This report was edited for publication by Ms. Lee T. Byrne, Information Technology Laboratory, WES.

Director of WES during the publication of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

	Page
PREFACE	i
CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT	vii
CHAPTER 1: COASTAL MODELING SYSTEM (CMS) OVERVIEW	1-1
PART I: INTRODUCTION	1-1
Background	1-1
Objective	1-2
PART II: IMPLEMENTATION OF CMS	1-4
Organization	1-4
Host Computer System	1-4
Model Support	1-5
Coastal Modeling System (CMS) User's Manual	1-6
Point of Contact	1-6
PART III: PRESENT CMS COMPONENTS	1-8
Chapter 2: Using the Coastal Modeling System	1-8
Chapter 3: Standard Project Hurricane (SPH)	1-8
Chapter 4: WES Implicit Flooding Mode (WIFM)	1-8
Chapter 5: Regional Coastal Processes Wave Propagation Model (RCPWAVE)	1-9
Chapter 6: Curvilinear Long-Wave Hydrodynamic Model (CLHYD)	1-9
Chapter 7: Spectral Wave Modeling Module of CMS (SHALWV)	1-9
Appendix A: CMSGRID	1-9
Appendix B: CMSUTIL	1-10
Appendix C: CMSPOST	1-10
Referemce	1-10
CHAPTER 2: USING THE COASTAL MODELING SYSTEM	2-1
PART I: ACCESS TO THE VAX 8800 AND CRAY Y-MP	2-1
Introduction	2-1
Computer Account Information	2-1
Login Procedure for the VAX 8800 and CRAY Y-MP	2-1
PART II: ACCESSING CMS	2-4
PART III: ILLUSTRATION OF CMS	2-7
Compilation	2-7
Execution	2-12
PART IV: CREATING AND EDITING INPUT FILES TO THE CMS	2-33
PART V: FILE TRANSFER PROCEDURE BETWEEN THE VAX 8800 AND CRAY Y-MP	2-34
CHAPTER 3: STANDARD PROJECT HURRICANE (SPH) MODEL THEORY AND PROGRAM DOCUMENTATION	3-1
PART I: INTRODUCTION	3-1

PART II: COMPUTATIONAL TECHNIQUE.................................. 3-3

PART III: DETERMINATION OF HURRICANE PARAMETERS................ 3-12

Parameters for the SPH.. 3-12
Parameters for Historical Storms.................................... 3-21

PART IV: DISCUSSION OF INPUT DATA REQUIREMENTS................. 3-23

Model Control Specifications.. 3-23
Wind-Field Specification.. 3-29
Output Specification.. 3-32

PART V: DEFINITION OF INPUT DATA FORMAT........................ 3-35

PART VI: TEST PROBLEMS... 3-38

Test Problem 1.. 3-41
Test Problem 2.. 3-50

REFERENCES... 3-60

APPENDIX 3-A: SPH DATA SPECIFICATION RECORDS....................... 3-61

CHAPTER 4: WES IMPLICIT FLOODING MODEL (WIFM) THEORY AND PROGRAM DOCUMENTATION.. 4-1

PART I: INTRODUCTION.. 4-1

PART II: SHALLOW-WATER WAVE EQUATION............................ 4-3

Assumptions and Limitations... 4-3
Governing Equations... 4-4
Grid System... 4-10
Computational Technique... 4-12
Boundary Conditions... 4-16

PART III: DEFINITION OF INPUT DATA FORMAT...................... 4-19

PART IV: DISCUSSION OF INPUT DATA REQUIREMENTS................. 4-22

Model Control Specifications.. 4-22
Grid Description.. 4-26
Physical Characteristics.. 4-29
Boundary Conditions... 4-37
Wind-Field Specifications... 4-47
Output Specification.. 4-49

PART V: ILLUSTRATIVE EXAMPLES.................................. 4-53

Tidal Forcing Simulation.. 4-54
Tidal Forcing Simulation with Nonlinear Terms....................... 4-60
Wind-Induced Setup Simulation....................................... 4-60
River Discharge Simulation.. 4-71
Storm Surge Example... 4-77

REFERENCES... 4-85

APPENDIX 4-A: WIFM DATA SPECIFICATION RECORDS...................... 4-87

CHAPTER 5: REGIONAL COASTAL PROCESSES WAVE PROPAGATION MODEL THEORY AND PROGRAM DOCUMENTATION................................. 5-1

PART I: INTRODUCTION.. 5-1

PART II: THEORETICAL DEVELOPMENT 5-3

Assumptions and Limitations 5-3
Governing Equations Outside the Surf Zone 5-3

PART III: DEFINITION OF INPUT DATA FORMAT 5-18

PART IV: DISCUSSION OF THE INPUT DATA REQUIREMENTS 5-21

Model Control Parameters 5-21
Grid Description 5-22
Physical Characteristics 5-23
Output Specifications 5-26

PART V: ILLUSTRATIVE EXAMPLES 5-28

Duck, North Carolina 5-28
Homer Spit, Alaska 5-32

REFERENCES 5-36

APPENDIX 5-A: RCPWAVE DATA SPECIFICATION RECORDS 5-37

APPENDIX 5-B: INPUT DATA SET FOR DUCK, NORTH CAROLINA 5-49

APPENDIX 5-C: INPUT DATA SET FOR HOMER SPIT, ALASKA 5-59

CHAPTER 6: CLHYD - A CURVILINEAR LONG WAVE HYDRODYNAMIC MODEL THEORY AND PROGRAM DOCUMENTATION 6-1

PART II: CLHYD MODEL FORMULATION 6-2

Assumptions and Limitations 6-2
Governing Equations 6-3
Grid Systems 6-8
Governing Equations in General Curvilinear Coordinates 6-13
Finite Differ
ds 6-14
Computational Theory 6-20

PART III: DEFINITION OF INPUT DATA FORMAT 6-26

PART IV: DISCUSSION OF INPUT DATA REQUIREMENTS 6-29

Model Control Specifications 6-29
Grid Description 6-33
Physical Characteristics 6-35
Boundary Conditions 6-39
Wind-Field Specifications 6-48
Output Specification 6-50

PART V: ILLUSTRATIVE EXAMPLES 6-54

Tidal-Forcing Simulation 6-55
Tidal-Forcing Simulation with Nonlinear Terms 6-61
Wind-Induced Setup Simulation 6-61
River Discharge Simulation 6-72
Orthogonal Curvilinear Grid Test Series 6-78
Static Basin Tests 6-78
Wind-Induced Setup Tests 6-79
Tidal-Forcing Test 6-82
Grid Resolution Tests Using Orthogonal Curvilinear Grids ... 6-85

REFERENCES 6-114

APPENDIX 6-A: TRANSFORMATION OF ADVECTION AND DISPERSION TERMS.. 6-117

APPENDIX 6-B: CLHYD DATA SPECIFICATION RECORDS.................. 6-123

APPENDIX 6-C: INPUT DATA SET FOR THE INDIAN RIVER INLET EXAMPLE. 6-159

CHAPTER 7: SHALWV THEORY AND PROGRAM DOCUMENTATION.................... 7-1

PART I: INTRODUCTION.. 7-1

PART II: DESCRIPTION OF THE SPECTRAL WAVE MODELING PROGRAMS..... 7-2

Theoretical Foundation.................................. 7-2
Advection Terms... 7-3
Source Terms.. 7-4
Diffraction and Sheltering.............................. 7-6
Initial and Boundary Conditions......................... 7-7
Preprocessing Options................................... 7-8
Warm Starts... 7-9
Computational Grids and Subgrids........................ 7-10
Assumptions and Limitations of SHALWV................... 7-10

PART III: STRUCTURE OF THE SPECTRAL WVE MODELING MODULE......... 7-14

Introduction.. 7-14
Operational Structure of the SHALWV Branch.............. 7-14

PART IV: MODULE FUNCTIONS AND ROUTINES......................... 7-20

SHALWV Module Functions and Routines.................... 7-20
Input Descriptions...................................... 7-61
Function to Run Programs................................ 7-71
Function to Plot/Print SHALWV Output.................... 7-73

PART V: SPECTRAL WAVE MODELING MODULE FILE DESCRIPTIONS......... 7-76

SHALWV Files.. 7-76
File Descriptions and Data Formats...................... 7-76
Example Data Sets....................................... 7-94

REFERENCES.. 7-104

APPENDIX A: CMSGRID.. A-1

Introduction.. A-2
Computational Technique of Program MAPIT................ A-3
Generating Stretch Rectilinear Grids.................... A-9
Program MAPIT... A-14
Program DRAWIT.. A-25
Program LISTIT.. A-34
Reference... A-38

APPENDIX B: CMSUTIL.. B-1

Introduction.. B-2
Program TIDEGEN... B-2
Program TIDECON... B-11

APPENDIX C: CMSPOST.. B-1
Introduction.. C-2
Data Requirements....................................... C-2
Program HYDPLT.. C-13
Program HYDLST.. C-21

Program HYDADD.. C-27
Program SNAPVEC....................................... C-32
Program SNAPLST....................................... C-38
Program PROFPLT....................................... C-50

CONVERSION FACTORS, NON-SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
fathoms	1.8288	meters
feet	0.3048	meters
inches	25.4	milliters
knots (international)	0.5144444	meters per second
miles (US nautical)	1.852	kilometers
miles (US statute)	1.609347	kilometers
pounds (force) per square inch	6.894757	kilopascals

CHAPTER 1

COASTAL MODELING SYSTEM (CMS) OVERVIEW

PART I: INTRODUCTION

Background

1. Numerical modeling technology is increasingly being employed as a tool to study complex problems in many engineering disciplines. In the field of coastal engineering, processes studied with numerical models include: hydrodynamics and transport associated with astronomical tides, storm surges, and tsunamis; refraction, diffraction, shoaling and breaking of waves; wave-induced currents; shoreline change induced by littoral movement of sand; erosion caused by short-term severe storms; and the fate and stability of dredged material placed in open water.

2. Numerical models use sophisticated methodology to solve governing equations describing the physical processes of interest. When a physical process is well described by the specified equations, the numerical modeling technique is capable of providing accurate solutions to engineering problems. However, the model developer must take extreme care in implementing the equations in a numerical scheme, and the model must be thoroughly tested for a variety of conditions and compared with prototype measurements to ensure correct model operation. Of equal importance is the care the engineer must take in applying the model to a field problem by ensuring that the model's governing equations are appropriate for representing the dominant physical processes at the site. Also, errors in input specification could dramatically alter model results, and without diligent inspection of model output, the errors could go undetected.

3. The Coastal Engineering Research Center (CERC) has developed a number of numerical models that are used for studying a variety of coastal processes under existing and proposed configurations. Some of these models are large and complex and may require a substantial amount of input data and/or computing effort. The models usually have a battery of supporting software for creating computational grids, running the model on the host

computer, and evaluating large amounts of output from the simulations. Because of the complexity of the model software and the diversity of modifications to input data associated with individual applications, these models have required considerable effort to apply.

4. Traditionally, most of the models were developed by researchers as individual efforts to solve a specific problem. Consequently, models have used different input/output structures, have been sparsely documented, and have been frequently altered to accomplish application-specific tasks. In addition, each model had its own set of supporting utilities to plot results, reformat data, etc. Often code alterations resulted in several versions of the same model, each with specific or enhanced capabilities. This situation had the potential for introducing errors, either by engineers applying the wrong version of the model or by programmers inadvertently altering the operation of a previously tested portion of the model.

5. Because of these factors, some of the most useful models at CERC have also been the most difficult to apply; and in some cases, it was necessary for the model developer to oversee the specific application. This dependence on the model developer meant that he or she had less time to devote to providing improved models to solve Corps problems.

6. The condition of the models described above implied a need for:

a. Maintenance of a single version of each model.

b. Standardization of the model input/output processes.

c. A central location for using the models.

d. Versatile models capable of covering a wide range of problems at different sites by using model options.

e. Comprehensive model documentation in the form of a user's manual.

Objective

7. The Coastal Modeling System (CMS) is a software package aimed at organizing CERC's larger numerical models and their supporting software into a user-friendly system that is available to all Corps elements having a need to apply the supported modeling technology.

8. Several objectives are followed in developing and expanding CMS. Since some of the models share similar input requirements, output capability,

and procedural implementation, efforts are made to standardize these portions of the models as much as possible. This standardization promotes efficiency because coding effort is reduced, new users learn the models in the system more rapidly, and chances for errors in entering input or interpreting output are reduced because of user familiarity with the system structure.

9. Most numerical models are applied to specific areas by representing the spatial bathymetric and topographic features as depths or elevations on a matrix called a computational grid. In some instances, it is possible to share a common numerical grid between models. This commonality allows efficient application of several different models to the same site without additional effort in building new grids. Similarly, processing of model output data can proceed in the same manner for several different models. To the extent possible, models in CMS share the same numerical grids, utilities, plotting programs, post-processing routines, and job control files.

10. FORTRAN 77 programming language is used exclusively in the system software to ensure portability of the models and supporting programs to other computer systems. Graphics programs also make use of DISSPLA™ software. When appropriate, attempts are made to produce a code that is capable of being vectorized for efficient and economical use on vector array processing computers such as the CRAY Y-MP, where CMS resides.

11. Models selected for inclusion in CMS must be well advanced in their development, and they must have been rigorously tested over a wide range of conditions. In most cases, a selected model has already been applied to numerous field problems and, thus, has reached some level of maturity through careful application to the types of problems encountered by the Corps. Incorporation of these time-tested models into CMS involves modification to the input/output structure and, possibly, re-coding of sections to produce more efficient use of computer resources. Once included in CMS, the models are not expected to be modified unless errors are found or new features are added. Therefore, the models in CMS can be considered tested, reliable, and mature.

PART II: IMPLEMENTATION OF CMS

Organization

12. CMS software is organized into three major groups: models, supporting utilities, and procedure files that draw components together for execution. Several software elements use common algorithms, and efforts are made to place these software elements into shared libraries. This placement eliminates redundant software and reduces associated development costs.

13. Another level of organization concerns user interfaces to the software, which are arranged according to various activities encountered during a modeling endeavor. These major procedure files provide users access to the various CMS software elements on the available computers.

14. Although the models and supporting software are written in standard FORTRAN 77, library structures and procedure files are specific to the computer system hosting CMS. In addition, some plotting utilities rely on specific graphics software that resides on the host computer, and certain terminal/plotter configurations may be required to produce plots of the model output at the user's local site.

Host Computer System

15. Most models included in CMS, or targeted for addition to CMS, are both memory-intensive and computationally intensive, requiring use of large supercomputers for efficient operation. It is possible to run some of the models on smaller minicomputers, but double precision would probably be necessary to avoid accumulated round-off errors, and applications could take from several hours to several days of CPU time on the smaller machines.

16. To satisfy the objective of Corps-wide access to the models, initial installation of CMS was on a mainframe computer operated by Scientific Information Services (SIS), formerly CYBERNET, which provided Corps-wide mainframe and supercomputer service. Now, with the installation of a CRAY Y-MP at the US Army Engineer Waterways Experiment Station (WES), Corps-wide access is available, and CMS has been transferred to that system to take advantage of reduced costs and the likelihood of a permanent home for CMS.

17. Corps personnel have access to the CRAY Y-MP through several communication networks. Presently, the supercomputer can be accessed through INTERNET, MILNET, ARPANET, ASNET, SURANET, BITNET, NSFNET, through a 1200, 2400, or 9600 baud modem, dedicated line, or the "front end" VAX 8800 computer.

18. Generally, CMS users are not required to learn the operating system associated with the supercomputer (UNICOS) because most of the job control commands normally required to submit models and data files to the computer for execution are accomplished by the CMS procedure files. This setup reduces learning time appreciably and minimizes errors caused by improper commands. However, users must be able to manipulate files, create and edit ASCII files, and download output files to a printer or plotter. These functions are easily mastered, and manuals are available to all Corps users of the CRAY Y-MP at a nominal fee by contacting the Information Technology Laboratory (ITL) Research Library, Ms. Susan Hicks (601) 634-2296. Presently there are 26 CRAY manuals covering such topics as UNICOS User Commands, CFT77 Reference, UNICOS Support Tools, and UNICOS Symbolic Debugging.

Model Support

19. Including a model in CMS represents a technology transfer from CERC to the field. CERC will maintain the CMS on the WES CRAY Y-MP and will provide support services to Corps users of the system. Support includes correcting recognized flaws in the codes, updating the models with new capabilities and technology, improving the user interface to the models, improving graphics and visualization capabilities, updating the *User's Manual* to reflect changes to the models and/or CMS, conducting periodic workshops for Corps personnel, and providing telephone support services.

20. Additionally, CERC staff can assist Corps personnel in applications of the CMS via "one-stop services" or by direct participation in site-specific studies. One-stop service is intended to address questions or problems that arise during field application of a model in CMS. Usually, these questions can be satisfactorily resolved in a short time over the telephone. More involved questions requiring a substantial effort by CERC engineers or scientists may require reimbursement. Experience at CERC indicates that field

application of these models usually requires a significant initial consulting effort by CERC engineers until experience has been gained by the field user.

Coastal Modeling System (CMS) User's Manual

21. The *Coastal Modeling System (CMS) User's Manual* is intended to be an evolving document, and it is structured in a modular fashion, much like the modeling system itself. Individual numerical models and major supporting utility software are documented in separate chapters. Attempts are made to structure all chapters in a similar format to facilitate learning the system models.

22. The unbound format of the user's manual allows efficient and cost-effective updating of the manual as models are added to CMS, and it allows users to remove chapters for convenient reference during model applications. The documentation for each new model will be an added chapter to the *CMS User's Manual*. Updates will also include additions of (or alterations to) utilities and procedures.

23. Initial distribution of the *CMS User's Manual* will be to all Corps Divisions and Districts with coastal interests. A register of all manuals distributed within the Corps of Engineers will be maintained by CERC, and updates will be provided for all Corps-registered copies of the manual.

24. Training on the usage of CMS and on application of specific models within CMS is accomplished during periodic workshops. Workshop participants, especially new users, will be introduced to CMS. Each workshop will demonstrate sign-on procedures, building input data files, file transfer methods, accessing CMS, running workshop-specific models, and post-processing model results. Technical presentations of workshop specific models will also be given. More intensive training can be provided at CERC as part of joint field applications between CERC and personnel from a field activity.

Point of Contact

25. Each model residing in CMS has a CERC point of contact (POC). Most often that person is the model developer or someone with extensive experience in applying the model. Table 1-1 provides POC's for models presently included in CMS. This table will be updated periodically to assure that it continues

to be a useful reference for CMS users. The modules listed in column 1 of Table 1-1 are briefly described in Part III of this chapter and are extensively documented in later chapters.

Table 1-1

CERC Points of Contact

Module	Point of Contact	Office Symbol	Phone Number
CMS general inquiries	Ms. Mary A. Cialone	CEWES-CR-P	601-634-2139
Using CMS	Ms. Lucy W. Chou	CEWES-CR-P	601-634-2843
SPH	Mr. Dave J. Mark	CEWES-CR-P	601-634-2094
WIFM	Ms. Mary A. Cialone	CEWES-CR-P	601-634-2139
RCPWAVE	Ms. Mary A. Cialone	CEWES-CR-P	601-634-2139
CLHYD	Ms. Mary A. Cialone	CEWES-CR-P	601-634-2139
SHALWV	Dr. Robert E. Jensen	CEWES-CR-O	601-634-2101
CMSGRID	Ms. Mary A. Cialone	CEWES-CR-P	601-634-2139
CMSUTIL	Ms. Lucy W. Chou	CEWES-CR-P	601-634-2843
CMSPOST	Ms. Lucy W. Chou	CEWES-CR-P	601-634-2843

PART III: PRESENT CMS COMPONENTS

26. The following briefly describes the numerical models, major utility software, and major procedures currently in the Coastal Modeling System.

Chapter 2: Using the Coastal Modeling System

27. This chapter provides information on execution of the CMS on the WES CRAY Y-MP. The new user should refer to this chapter to learn to compile or run a model for a specific application. Once the user becomes familiar with the system, this chapter can be used as a quick reference.

Chapter 3: Standard Project Hurricane (SPH)

28. The numerical model SPH is a parametric model for representing wind and atmospheric pressure fields generated by hurricanes. It is based on the Standard Project Hurricane criteria developed by the National Oceanic and Atmospheric Administration (NOAA 1979), and the model's primary output are hurricane-generated wind fields that can be used in storm surge modeling. It can be run separately, or it can be invoked from within the WES Implicit Flooding Model (WIFM).

Chapter 4: WES Implicit Flooding Model (WIFM)

29. The numerical model WIFM solves the vertically integrated Navier-Stokes equations in stretched Cartesian coordinates. The model simulates shallow-water, long-wave hydrodynamics such as tidal circulation, storm surges, and tsunami propagation. WIFM contains may useful features for studying these phenomena, such as moving boundaries to simulate flooding/drying of low-lying areas and subgrid flow boundaries to simulate small barrier islands, jetties, dunes, or other structural features. The model may be driven at the outer boundary by tide elevations, flow velocities, specification of uniform flux, or inverted barometer effects. WIFM also accepts wind fields for including the effects of wind stress during hurricanes or other strong storm systems.

Chapter 5: Regional Coastal Processes Wave Propagation Model (RCPWAVE)

30. The numerical model RCPWAVE is a short-wave model used to predict linear, plane wave propagation over an open coast region of arbitrary bathymetry. RCPWAVE uses linear wave theory because it has been shown to yield fairly accurate first-order solutions to wave propagation problems at a relatively low cost. Refractive and bottom-induced diffractive effects are included in the model; however, the model cannot treat diffraction caused by surface-piercing structures. This model does not include nonlinear wave effects or a spectral representation of irregular waves.

Chapter 6: Curvilinear Long-Wave Hydrodynamic Model (CLHYD)

31. Numerical model CLHYD simulates shallow-water, long-wave hydrodynamics such as tidal circulation and storm surge propagation. CLHYD can simulate flow fields induced by wind fields, river inflows/outflows, and tidal forcing. CLHYD is similar to WIFM, with the added feature of operating on a boundary-fitted (curvilinear) grid system. However, CLHYD cannot simulate flooding/drying of low-lying areas as WIFM can. This feature will be incorporated in a later release of CLHYD.

Chapter 7: Spectral Wave Modeling Module of CMS (SHALWV)

32. The numerical model SHALWV is a time-dependent spectral wind-wave model for computing a time-history of wind-generated waves. The model solves the inhomogeneous energy balance equation using finite difference methods. It simulates the growth, decay, and transformation of a wave field over a spatial area (i.e., an ocean basin, bay, or lake) for a given time period. SHALWV can simulate the wave climate for a specific storm or idealized events, such as a standard project hurricane.

Appendix A: CMSGRID

33. Grid development is a major part of successfully applying a numerical model to a specific site. Module CMSGRID contains software used in the generation of stretched coordinate, rectilinear computational grids for

several models in CMS. The software employs sophisticated techniques that allow concentration of grid cells in regions of interest, or where geographic features are irregular, and wider spacing of grid cells in areas where conditions are not expected to change rapidly. The ability to generate variably spaced grids provides economy in computational time and costs. Generated grids can be plotted to scale on Mylar for overlaying bathymetric charts to obtain depths and elevations.

Appendix B: CMSUTIL

34. Module CMSUTIL contains useful programs that supplement numerical models in CMS. Presently, there are two programs in this module: a program to determine tidal constituents from a time-history of tidal elevations, and a program to generate a time series of water elevations from tidal constituent input.

Appendix C: CMSPOST

35. Most numerical models generate large output files containing results saved at user-specified grid cells and time-steps during the simulation. Module CMSPOST contains post-processing plotting packages that plot the model output for comparison and analysis purposes. Four basic types of plotting are available: (a) time-histories of field arrays such as water surface elevation or velocity at selected grid points, (b) "snapshots" of the entire flow field at a given instant in time, (c) wave ray plots, and (d) profile plots that show the spatial variation of a model variable at an instant in time.

Reference

National Oceanic and Atmospheric Administration. 1979. "Meteorological Criteria for Standard Project Hurricane and Probable Maximum Hurricane Wind Fields, Gulf and East Coasts of the United States," Technical Report NWS 23, National Weather Service, Washington, DC.

CHAPTER 2

USING THE COASTAL MODELING SYSTEM

PART I: ACCESS TO THE VAX 8800 AND CRAY Y-MP

Introduction

1. The Coastal Modeling System (CMS) is available to all Corps elements through the CRAY Y-MP supercomputer that resides at the Information Technology Laboratory (ITL), US Army Waterways Experiments Station (WES). This chapter provides a detailed description of the steps necessary to use the CMS. In addition, sample runs of several models in the CMS are given for illustration.

Computer Account Information

2. A computer account for both the VAX 8800 and CRAY Y-MP can be obtained by calling the Customer Assistance Center (CAC) at WES (601) 634-4400. Although it is no longer necessary to have a VAX 8800 account to access the CRAY Y-MP, it is recommended that the user obtain a VAX 8800 account for data manipulation purposes. Cost for usage of the CRAY is $500/hr and $100/hr for the VAX 8800. Disk storage will be billed at the rate of $1.60/megaword-day (1 megaword = 8 megabytes) on both systems. A DA 448 - Military Interagency Purchasing Request (MIPR) or a DA 2544 funding document must be sent to WES-CAC before computer accounts can be set up on the CRAY or VAX.

Login Procedure for the VAX 8800 and CRAY Y-MP

3. A user can log onto the VAX 8800 through the INTERNET network or a modem. (INTERNET is a national collection of networks including MILNET, NSFNET, ARPANET, ASNET, SURANET, and BITNET.) The login procedure is as follows:

a. To log onto the ITL VAX 8800 through the INTERNET network, type in the following command at your remote workstation:

```
telnet wesim3.wes.army.mil     <ret>
```

or

telnet 134.164.4.1 <ret>

where 134.164.4.1 is the INTERNET address for the ITL VAX 8800.

b. To log onto the ITL VAX 8800 through a 1200 or 2400 modem:

(1) Dial (601) 634-4458 or FTS 542-4458 to connect to the terminal server.

(2) Press the RETURN key twice after the terminal server is connected.

(3) Type in the command:

c wesim3 <ret>

A 9600 baud modem can also be used. The telephone number for the 9600 baud rate is (601) 634-4426 or FTS 542-4426.

4. Once connected to the ITL VAX 8800, a user can log onto the CRAY Y-MP from the VAX 8800. The user can also connect directly to the CRAY Y-MP, if so desired. It should be noted that the UNICOS operating system is case sensitive; therefore, terminal keyboard CAPS LOCK should remain "off" for all CRAY Y-MP sessions.

a. To log onto the CRAY Y-MP through the VAX 8800, type:

telnet larry <ret>

b. To log onto the CRAY Y-MP through the INTERNET network, type:

telnet larry.wes.army.mil <ret>

or

telnet 134.164.8.2 <ret>

where 134.164.8.2 is the INTERNET address of the WES CRAY Y-MP.

c. To log onto the CRAY Y-MP through a modem:

(1) Dial (601) 634-4458 or FTS 542-4458 to connect to the terminal server.

(2) Press the RETURN key twice after the terminal server is connected.

(3) Type in the command:

telnet larry <cr>

The computer will then prompt the user for the username and password for his/her account.

PART II: ACCESSING CMS

5. CMS is a command procedure file or "shell script" for using models in CMS. The script serves two purposes: (a) it builds the necessary preprocessor file and compiled source code of the desired model, and (b) it loads, links, and executes the model. The steps necessary to use CMS are as follows:

a. To access CMS, type in the command:

```
/u3/h2crplc0/cms
```

Note that CMS resides on the CRAY Y-MP account **/u3/h2crplc0**; therefore, the user must provide this path name when accessing CMS. The computer will then prompt the user with a series of questions, in menu form, concerning:

(1) The desired model name (see Table 2-1).

(2) The model procedure name, which is either **BUILD** (or **build**), **RUN** (or **run**), or **EXIT** (or **exit**) where "**build**" is used for compiling and linking the model, "**run**" is used for model execution, and "**exit**" is used to terminate the CMS session.

(3) The input and output filenames. Filenames should be limited to 8 digits with 3-digit extensions if they are to be transferred to a personal computer (PC). It is recommended that input files be created and edited on the VAX 8800 or on the user's PC and transferred to the CRAY Y-MP for CMS simulations.

Following the entry of all output filenames, CMS launches a batch job to the CRAY Y-MP, for example:

```
Request 1234.larry submitted to queue:prime
```

where 1234 is the job number assigned by the CRAY Y-MP for the particular run. The batch queue selected by the system, in this case "prime," is based on the estimated execution time of the job.

b. To check the job status after it is submitted to the CRAY Y-MP, the user can type in the UNICOS command:

```
qstat -a          <ret>
```

where -a indicates status of the current user's batch jobs only. If the batch job is still in the batch queue, the computer will respond:

```
1234.larry   wifm_build.com  h2crpmc0  primea@larry
no pipe queue entries
no device queue entries
```

indicating that the job is still in the batch queue. If the job is completed (compiled or executed), the computer will respond:

```
no batch queue entries
no pipe queue entries
no device queue entries
```

6. To save computing time and expenses, CMS is divided into two parts: (a) compilation and (b) execution. The user can change certain values in the input data set without recompiling the model. However, changing certain crucial values will require recompilation. After the job's completion, system output files will be generated and will reside in the user's working directory. The two files generated after model compilation are named **Model_bu.exxxx** and **Model_bu.oxxxx**, and the two system output files generated after model execution are **Model_ru.exxxx** and **Model_ru.oxxxx**. The **xxxx** is the 4 or 5-digit job number assigned by the system (depending on the CRAY Y-MP schedule) for the particular run. The **.e** file contains compiling or execution error messages while the **.o** file contains a summary report of the job accounting information. Example filenames are given in Table 2-1.

Table 2-1

Example Filenames

Example Procedure	Example File Produced
Build WIFM	WIFM_BU.E1234 WIFM_BU.01234
Run WIFM	WIFM_RU.E5678 WIFM_RU.05678

7. To read the error messages or the accounting report, the user can type the UNICOS command

pg file_name <ret>

where "file_name" is a filename in the form mentioned previously and in Table 2-1. The pg command displays the text file on a terminal, one screenful at a time. The user can press the return key to view another screenful or q to terminate viewing of the particular file. The UNICOS command cat is not recommended for this purpose because the entire file will scroll onto the terminal screen and it is difficult to terminate the scrolling process.

Compilation

8. For illustrative purposes, model WIFM was selected for compilation. Compilation of any of the other models in the CMS is identical to the procedure given below. The user:

- a. Invokes CMS.
- b. Selects the name of the desired model.
- c. Selects "BUILD" to compile and link the desired model.
- d. Enters the input filename to be used for the subsequent model run.

9. CMS resides on the CRAY Y-MP account /u3/h2crplc0; therefore, the user must provide this path name when accessing CMS. To compile model WIFM, the user (h2crplcl for the following examples) invokes CMS by entering the information shaded below (step a). It should be noted that user entries are shown as shaded and CMS response "screens" are shaded boxes. The information preceding the shaded command in step a (h2crplcl:larry$) is a system prompt.

a. h2crplcl:larry$/u3/h2crplc0/cms

The CMS responds:

```
            W E L C O M E   T O . . .

      XXXXX          X     X        XXXXX
     X     X         XX   XX       X     X
     X               X X X X       X
     X               X  X  X        XXXXX
     X               X     X             X
     X     X         X     X       X     X
      XXXXX          X     X        XXXXX

                Return for more...
```

```
************************************************************************
*                        C M S   COMPONENTS                            *
************************************************************************
* Options:                                                             *
*                                                                      *
* CMSGRID (Maps, plots, and lists the numerical grid) -------> 1       *
*                                                                      *
* CMSMODEL (Compiles, links, loads, and executes                       *
*                 numerical models) -----------------------> 2         *
*                                                                      *
* CMSPOST (Plots and lists model outputs) -----------------> 3         *
*                                                                      *
* CMSUTIL (Additional "utility" programs) -----------------> 4         *
*                                                                      *
* Exit CMS ------------------------------------------------> e         *
************************************************************************
```

Enter option number -----------------------> 2

The CMS responds:

```
  CCCCC   M     M   SSSSS   M     M    OO    DDDDD   EEEEE  L
 C        MM   MM  S        MM   MM   O  O   D    D  E      L
C         M M M M  S        M M M M  O    O  D     D E      L
C         M  M  M   SSSS    M  M  M  O    O  D     D EEE    L
C         M     M       S   M     M  O    O  D     D E      L
 C        M     M       S   M     M   O  O   D    D  E      L
  CCCCC   M     M  SSSSS    M     M    OO    DDDDD   EEEEE  LLLLL


                     Return for more. . .
```

```
*********************************************************************
*                                                                   *
*              USING THE COASTAL MODELING SYSTEM                    *
*                                                                   *
*********************************************************************
*                                                                   *
*  Options:                                                         *
*                                                                   *
*    On-Line Help ---------------------------------------------> 1  *
*                                                                   *
*    Enter CMSMODEL Module -----------------------------------> 2  *
*                                                                   *
*    Return to Main Menu -------------------------------------> 3  *
*                                                                   *
*********************************************************************
```

Enter option number -----------------> **2**

The CMS responds:

```
************************************************************
*                                                          *
*              Models Presently in System                  *
************************************************************

   CLHYD:      Curvilinear Hydrodynamic 2-Dimensional Model

   RCPWAVE:    Regional Coastal Processes Wave Model

   SPH:        Standard Project Hurricane Wind Model

   WIFM:       WES Implicit Flooding Model

   SWM:        SPECTRAL WAVE MODELING
               SHALWV:  Time Dependent Wave Model
               STWAVE:  Time Independent Wave Model

   EXIT:       Terminate computer session
```

The user is prompted to enter the name of the model desired:

b. **Enter name of model** **wifm**

The CMS responds:

```
W     W     I     FFFFFF     M     M
W     W     I     F          MM   MM
W     W     I     F          M M M M
W  W  W     I     FFFF       M  M  M
W W W W     I     F          M     M
WW   WW     I     F          M     M
W     W     I     F          M     M


          Return for more...
```

```
Select Model Procedure:

    BUILD - compile and link model
    RUN   - execute model
    EXIT  - terminate computer session
```

For this example WIFM is compiled and linked by responding to the CMS prompt with:

c. Enter procedure name **build**

The user is prompted for the input data set as follows:

d. Enter name of input data file **/u3/h2crplcl/wifm/test/mock.inpl**

Note that the name of the user's input data file (**/wifm/test/mock.inpl**) may be different from that given in step d. The system responds:

```
Request 2710.larry submitted to queue: prime.
**** END OF CMS PROCEDURE
```

This procedure launches a batch job (number 2710) to the CRAY Y-MP.

10. To check the status of the batch job, the user types:

h2crplcl:larry$ qstat -a

When the system responds:

```
no batch queue entries
no pipe queue entries
no device queue entries
```

then the batch job is completed.

11. To check the status of files produced by the batch job, the user types the following to check the status of the error file:

```
h2crplcl:larry$ ls -l *.e*
-rw-------    1 h2crplcl CERC          0 Aug 13 12:54 wifm_bu.e2710
```

and the following to check the status of the output files:

```
h2crplcl:larry$ ls -l *.o*
-rw-------    1 h2crplcl CERC       1556 Aug 13 12:54 wifm_bu.o2710
-rw-------    1 h2crplcl CERC     450504 Aug 13 12:54 wifmall.c
```

The .e2710 file contains compiling error messages, and the .o2710 file contains a summary report of the job accounting information.

12. To view the compiling error message, the user types:

```
h2crplcl:larry$ pg wifm_bu.e2710
```

In this case, there are no error messages. If the user encounters compilation errors, he or she should call the Coastal Engineering Research Center (CERC) CMS representative.

13. To view the summary report of the job accounting information, the user types:

```
h2crplcl:larry$ pg wifm_bu.o2710
```

The system responds:

```
              USAEWES Information Technology Laboratory
                   CRAY Y-MP 8/6128  (UNICOS 5.1)

Questions/problems/comments --> call Customer Assistance at
(601)634-4400 or send mail to cag@wesim3

%% Use 'bull' for information on tapes, printer, and other news. %%



Job Accounting - Summary Report
===============================

Job Accounting File Name         : /tmp/nqs.+++++0+eL/.jacct1166
Operating System                 : sn1022 larry 5.1 1022.15 CRAY Y-MP
User Name (ID)                   : h2crplc1 (1458)
Group Name (ID)                  : CERC (105)
Account Name (ID)                : A-00000 (0)
Job Name (ID)                    : wifm_build.com (1166)
Report Starts                    : 08/13/90 12:53:20
Report Ends                      : 08/13/90 12:54:02
Elapsed Time                     :          42      Seconds
User CPU Time                    :          36.2225 Seconds
System CPU Time                  :           0:8803 Seconds
I/O Wait Time (Locked)           :           0:1809 Seconds
I/O Wait Time (Unlocked)         :           0.6861 Seconds
CPU Time Memory Integral         :          35.9472 Mword-seconds
SDS Time Memory Integral         :           0.0000 Mword-seconds
I/O Wait Time Memory Integral    :           0.2086 Mword-seconds
Data Transferred                 :           2.1089 Mbytes
Logical I/O Requests             :         518
Physical I/O Requests            :         454
Number of Commands               :          16
Billing Units                    :           0.0000
```

Execution

14. Models WIFM, SPH, CLHYD, and HARBD were selected for execution. The user is referred to Chapter 7 for illustrations of SHALWV. To execute model WIFM, the user types:

a. h2crplc1:larry$ /u3/h2crplc0/cms

The CMS responds:

```
           W E L C O M E   T O . . .

     XXXXX          X     X        XXXXX
    X     X         XX   XX       X     X
    X               X X X X       X
    X               X  X  X        XXXXX
    X               X     X             X
    X     X         X     X       X     X
     XXXXX          X     X        XXXXX


                Return for more...
```

```
*********************************************************************
*                          C M S   COMPONENTS                       *
*********************************************************************
*  Options:                                                         *
*                                                                   *
*  CMSGRID (Maps, plots, and lists the numerical grid) -------> 1 *
*                                                                   *
*  CMSMODEL (Compiles, links, loads, and executes                  *
*                numerical models) -------------------------> 2 *
*                                                                   *
*  CMSPOST (Plots and lists model outputs) -------------------> 3 *
*                                                                   *
*  CMSUTIL (Additional "utility" programs) -------------------> 4 *
*                                                                   *
*  Exit CMS ----------------------------------------------------> e *
*********************************************************************
```

Enter option number -------------------------> 2

The CMS responds:

```
  CCCCC   M     M   SSSSS  M     M    OO    DDDDD   EEEEE  L
 C        MM   MM   S      MM   MM   O  O   D    D  E      L
C         M M M M   S      M M M M  O    O  D     D E      L
C         M  M  M    SSSS  M  M  M  O    O  D     D EEE    L
C         M     M        S M     M  O    O  D     D E      L
 C        M     M        S M     M   O  O   D    D  E      L
  CCCCC   M     M   SSSSS  M     M    OO    DDDDD   EEEEE  LLLLL


                      Return for more. . .
```

```
***********************************************************************
*                                                                     *
*                  USING THE COASTAL MODELING SYSTEM                  *
*                                                                     *
***********************************************************************
*                                                                     *
*  Options:                                                           *
*                                                                     *
*    On-Line Help ------------------------------------------->  1    *
*                                                                     *
*    Enter CMSMODEL Module ---------------------------------->  2    *
*                                                                     *
*    Return to Main Menu ------------------------------------>  3    *
*                                                                     *
***********************************************************************
```

```
Enter option number  ----------------->  2
```

The CMS responds:

```
************************************************************
*            Models Presently in System                    *
************************************************************
   CLHYD:      Curvilinear Hydrodynamic 2-Dimensional Model

   RCPWAVE:    Regional Coastal Processes Wave Model

   SPH:        Standard Project Hurricane Wind Model

   WIFM:       WES Implicit Flooding Model

   SWM:        SPECTRAL WAVE MODELING
               SHALWV:  Time Dependent Wave Model
               STWAVE:  Time Independent Wave Model

   EXIT:       Terminate computer session
```

The user is prompted to enter the name of the model desired:

b. Enter name of model **wifm**

The CMS responds:

```
W     W     I     FFFFFF     M     M
W     W     I     F          MM   MM
W     W     I     F          M M M M
W  W  W     I     FFFF       M  M  M
W W W W     I     F          M     M
WW   WW     I     F          M     M
W     W     I     F          M     M



             Return for more...
```

```
Select Model Procedure:

    BUILD - compile and link model
    RUN   - execute model
    EXIT  - terminate computer session
```

For this example WIFM is executed by responding to the CMS prompt with:

```
c.  Enter procedure name run
```

The user is prompted for the input and output data sets as follows. Note that the names of the user's input and output files may differ from those given in steps d, f, g, and h. Example input and output files can be found in Chapter 4.

```
d.  Enter name of input data file /u3/h2crplcl/wifm/test/mock.inp1
```

A hotstart simulation indicates that model results (water surface elevations and velocities) have been saved from a previous simulation and are to be used as initial conditions for the present simulation:

```
e.  Is this a HOTSTART simulation?
    Enter y[es] or n[o] to continue n

f.  Enter the name of the output data file mock.out
    outdeck = mock.out
```

Hydrograph data are time-histories of model results (i.e., water surface elevations and velocities) at selected (gage) points in the computational domain.

```
g.  Do you want to save hydrographic data?
    Enter y[es] or n[o] to continue y
    Enter the name of the hydrograph data file mock.hyd1
```

A snapshot is a "picture" of the flow field for the entire grid or a portion of the grid at a given instant in time.

```
h.  Do you want to save snapshots?
    Enter y[es] or n[o] to continue y
    Enter the name of the snapshot data file mock.snp1
```

Hotstart data (water surface elevations and velocities) can be saved for the entire computational domain for use in a subsequent simulation.

```
i.  Do you want to save hotstart data?
    Enter y[es] or n[o] to continue n
```

The system responds:

```
Request 2713.larry submitted to queue: prime.
**** END OF CMS PROCEDURE
```

This procedure launches a batch job (number 2713) to the CRAY Y-MP.

15. In order to check the status of the batch job, the user types:

```
h2crplcl:larry$ qstat -a
```

If the job is still in the batch queue, the computer will respond:

```
2713.larry wifm_run.com h2crpmc0 prime@larry
no pipe queues entries
no device queue entries
```

When the system responds:

```
no batch queue entries
no pipe queue entries
no device queue entries
```

then the batch job is completed.

16. To check the status of files produced by the batch job, the user types:

```
h2crplcl:larry$ ls -l *.e*
-rw-------    1 h2crplcl CERC          0 Aug 13 12:54 wifm_bu.e2710
-rw-------    1 h2crplcl CERC         73 Aug 13 13:01 wifm_ru.e2713
```

and

```
h2crp.cl:larry$ ls -l *.o*
-rw-------    1 h2crplcl CERC     140567 Aug 13 13:01 mock.out
-rw-------    1 h2crplcl CERC          0 Aug 13 13:01 wifm.out
-rw-------    1 h2crplcl CERC       1556 Aug 13 12:54 wifm_bu.o2710
-rw-------    1 h2crplcl CERC       1554 Aug 13 13:01 wifm_ru.o2713
-rw-------    1 h2crplcl CERC     450504 Aug 13 12:54 wifmall.o
```

The .e file contains compiling error messages, and the .o file contains a summary report of the job accounting information.

17. To view the system error messages, the user types:

```
h2crplcl:larry$ pg wifm_ru.e2713
```

The system responds:

```
STOP
CP:  7.886s, Wallclock:  7.987s,   16.5% of 6-CPU Machine
```

In this case, there are no error messages. Types of errors one might encounter include:

```
Floating exception
TB001 - BEGINNING OF TRACEBACK
      - $TRBK    WAS CALLED BY  f_sig   AT 234471a (LINE NUMBER  235)
      - f_sig    WAS CALLED BY CALLFUNC AT 204414c
      - CALLFUNC WAS CALLED BY WIFMXY   AT  31402a
      - WIFMXY   WAS CALLED BY WIFM     AT    664c (LINE NUMBER  236)
      - WIFM     WAS CALLED BY $START$  AT    136d
TB002 - END OF TRACEBACK
```

which indicates that a "floating divide by zero" or a dimensioning problem was encountered during the simulation. If this occurs, call the CERC CMS representative. Input errors would not be indicated in the system error file (**wifm_ru**.e2713), but can be found in the model output file (**mock.out**). A sample output file with errors should be examined as shown in Table 2-2. The underlined information in Table 2-2 is typed by the user, making use of the CRAY line editor (see UNICOS primer SG-2010 C).

Table 2-2

Example of an Input Error

```
ed mock.out
$                      to go to the end of the file
***** PROGRAM ABORTING !!!!!
n                      to determine the line number at the end of file
242  ***** PROGRAM ABORTING !!!!!
230,$p                 to type lines 230 to the end of file
*** FATAL ERRORS =    2      WARNINGS =  0
***** SYSTEM SPECIFICATION -- "FNGLISH  " NOT RECOGNIZED !!!!!
***** PROGRAM ABORTING !!!!!
```

18. To view the summary report of the job accounting information, the user types:

h2crplcl:larry$ pg wifm ru.o2713

The system responds:

```
                    USAEWES Information Technology Laboratory
                          CRAY Y-MP 8/6128  (UNICOS 5.1)

Questions/problems/comments --> call Customer Assistance at
(601)634-4400 or send mail to cag@wesim3

%% Use 'bull' for information on tapes, printer, and other news. %%

Job Accounting - Summary Report
===============================

Job Accounting File Name          : /tmp/nqs.+++++0+e0/.jacctl181
Operating System                  : sn1022 larry 5.1 1022.15 CRAY Y-MP
User Name (ID)                    : h2crplcl (1458)
Group Name (ID)                   : CERC (105)
Account Name (ID)                 : A-00000 (0)
Job Name (ID)                     : wifm_run.com (1181)
Report Starts                     : 08/13/90 13:01:40
Report Ends                       : 08/13/90 13:01:51
Elapsed Time                      :          11      Seconds
User CPU Time                     :            8.3513 Seconds
System CPU Time                   :          0:1963 Seconds
I/O Wait Time (Locked)            :          1:3230 Seconds
I/O Wait Time (Unlocked)          :          1.0556 Seconds
CPU Time Memory Integral          :          2.8742 Mword-seconds
SDS Time Memory Integral          :          0.0000 Mword-seconds
I/O Wait Time Memory Integral     :          0.3517 Mword-seconds
Data Transferred                  :          4.5823 Mbytes
Logical I/O Requests              :         189
Physical I/O Requests             :         260
Number of Commands                :          11
Billing Units                     :          0.0000
```

19. To execute model SPH, the user types:

    a. h2crplcl:larry$ /u3/h2crplc0/cms

The CMS responds:

```
W E L C O M E   T O . . .

 XXXXX        X     X       XXXXX
X     X       XX   XX      X     X
X             X X X X      X
X             X  X  X       XXXXX
X             X     X            X
X     X       X     X      X     X
 XXXXX        X     X       XXXXX


Return for more...
```

```
**********************************************************************
*                         C M S   COMPONENTS                         *
**********************************************************************
*  Options:                                                          *
*                                                                    *
*  CMSGRID (Maps, plots, and lists the numerical grid)  -------> 1 *
*                                                                    *
*  CMSMODEL (Compiles, links, loads, and executes                    *
*                 numerical models)  -------------------------> 2 *
*                                                                    *
*  CMSPOST (Plots and lists model outputs)  ------------------> 3 *
*                                                                    *
*  CMSUTIL (Additional "utility" programs)  ------------------> 4 *
*                                                                    *
*  Exit CMS  ------------------------------------------------> e *
**********************************************************************
```

```
Enter option number  ---------------->
```

The CMS responds:

```
  CCCCC   M     M   SSSSS   M     M    OO     DDDDD    EEEEE  L
 C        MM   MM  S        MM   MM   O  O    D    D   E      L
C         M M M M  S        M M M M  O    O   D     D  E      L
C         M  M  M   SSSS    M  M  M  O    O   D     D  EEE    L
C         M     M       S   M     M  O    O   D     D  E      L
 C        M     M       S   M     M   O  O    D    D   E      L
  CCCCC   M     M  SSSSS    M     M    OO     DDDDD    EEEEE  LLLLL


                        Return for more. . .
```

```
*********************************************************************
*                                                                   *
*                 USING THE COASTAL MODELING SYSTEM                 *
*                                                                   *
*********************************************************************
*                                                                   *
*  Options:                                                         *
*                                                                   *
*    On-Line Help ------------------------------------------->  1  *
*                                                                   *
*    Enter CMSMODEL Module ---------------------------------->  2  *
*                                                                   *
*    Return to Main Menu ------------------------------------>  3  *
*                                                                   *
*********************************************************************
```

```
Enter option number ----------------> 2
```

The CMS responds:

```
*****************************************************************
*                  Models Presently in System                   *
*****************************************************************
   CLHYD:      Curvilinear Hydrodynamic 2-Dimensional Model

   RCPWAVE:    Regional Coastal Processes Wave Model

   SPH:        Standard Project Hurricane Wind Model

   WIFM:       WES Implicit Flooding Model

   SWM:        SPECTRAL WAVE MODELING
               SHALWV:  Time Dependent Wave Model
               STWAVE:  Time Independent Wave Model

   EXIT:       Terminate computer session
```

The user is prompted to enter the name of the model desired:

b. Enter name of model **sph**

The CMS responds:

```
 SSSSS      PPPPP      H     H
S     S     P    P     H     H
S           P    P     H     H
 SSSSS      PPPPP      HHHHHHH
      S     P          H     H
S     S     P          H     H
 SSSSS      P          H     H


          Return for more...
```

```
Select Model Procedure:

     BUILD - compile and link model
     RUN   - execute model
     EXIT  - terminate computer session
```

For this example SPH is executed by responding to the CMS prompt with:

c. Enter procedure name **run**

The user is prompted for the input and output data sets as follows. Note that the names of the users input and output files may differ from those given in steps d, e, and f. Example input and output files can be found in Chapter 3.

d. Enter the name of the input data file
   /u3/h2crplc0/cms/sph/exm/test_n.inp

e. Enter the name of the output data file **test_n.out**

Hydrograph data are time-histories of model results (i.e., wind velocities) at selected (gage) points in the computational domain.

f. Do you want to save hydrographic data?
   Enter y[es] or n[o] to continue **y**
   Enter the name of the hydrograph data file **test_n.hyd**

A snapshot is a "picture" of the flow field for the entire grid or a portion of the grid at a given instant in time.

g. Do you want to save snapshots?
   Enter y[es] or n[o] to continue **n**

The system responds:

```
Request 8640.larry subfitted to queue: prime.
**** END OF CMS PROCEDURE
```

20. To excute model RCPWAVE, the user types:

a. h2crplcl:larry$ [redacted]

The CMS responds:

```
            W E L C O M E   T O . . .

     XXXXX          X     X          XXXXX
    X     X         XX  X           X     X
    X               X X X X         X
    X               X  X  X          XXXXX
    X               X     X               X
    X     X         X     X         X     X
     XXXXX          X     X          XXXXX

                 Return for more...
```

```
*****************************************************************
*                         C M S   COMPONENTS                    *
*****************************************************************
*  Options:                                                     *
*                                                               *
*  CMSGRID (Maps, plots, and lists the numerical grid) -------> 1 *
*                                                               *
*  CMSMODEL (Compiles, links, loads, and executes               *
*                 numerical models) -------------------------> 2 *
*                                                               *
*  CMSPOST (Plots and lists model outputs) -------------------> 3 *
*                                                               *
*  CMSUTIL (Additional "utility" programs) -------------------> 4 *
*                                                               *
*  Exit CMS -------------------------------------------------> e *
*****************************************************************
```

Enter option number -------------------------> 2

The CMS responds:

```
  CCCCC   M     M   SSSSS   M     M    OO    DDDDD    EEEEE  L
 C        MM   MM   S       MM   MM   O  O   D    D   E      L
C         M M M M   S       M M M M  O    O  D     D  E      L
C         M  M  M   SSSS    M  M  M  O    O  D     D  EEE    L
C         M     M       S   M     M  O    O  D     D  E      L
 C        M     M       S   M     M   O  O   D    D   E      L
  CCCCC   M     M  SSSSS    M     M    OO    DDDDD    EEEEE  LLLLL


                      Return for more. . .
```

```
**********************************************************************
*                                                                    *
*                 USING THE COASTAL MODELING SYSTEM                  *
*                                                                    *
**********************************************************************
*                                                                    *
*  Options:                                                          *
*                                                                    *
*    On-Line Help  ------------------------------------------->  1  *
*                                                                    *
*    Enter CMSMODEL Module  ---------------------------------->  2  *
*                                                                    *
*    Return to Main Menu  ------------------------------------>  3  *
*                                                                    *
**********************************************************************
```

Enter option number ----------------->

The CMS responds:

```
*************************************************************
*                Models Presently in System                 *
*************************************************************
   CLHYD:      Curvilinear Hydrodynamic 2-Dimensional Model

   RCPWAVE:    Regional Coastal Processes Wave Model

   SPH:        Standard Project Hurricane Wind Model

   WIFM:       WES Implicit Flooding Model

   SWM:        SPECTRAL WAVE MODELING
               SHALWV:  Time Dependent Wave Model
               STWAVE:  Time Independent Wave Model

   EXIT:       Terminate computer session
```

The user is prompted to enter the name of the model desired:

b. Enter name of model rcpwave

The CMS responds:

```
RRRRR     CCCCC    PPPPP   W     W      A      V   V   EEEEEE
R    R   C     C   P    P  W     W     A A     V   V   E
R    R   C         P    P  W     W    A   A    V   V   E
RRRRR    C         PPPPP   W  W  W   AAAAAAA   V   V   EEEE
R  R     C         P       W W W W   A     A   V   V   E
R   R    C     C   P       WW   WW   A     A    V V    E
R    R    CCCCC    P       W     W   A     A     V     EEEEEE


                     Return for more...
```

```
Select Model Procedure:

    BUILD - compile and link model
    RUN   - execute model
    EXIT  - terminate computer session
```

For this example RCPWAVE is executed by responding to the CMS prompt with:

c. Enter procedure name run

The user is prompted for the input and output data sets as follows. Note that the names of the user's input and output files may differ from those given in steps d, e, f, and g. Example input and output file can be found in Chapter 5.

d. Enter name of input data file /u3/h2crplc0/cms/sph/exm/rcp.inp

The general output file can be given a default filename:

e. Enter the name of the output data file <ret>
Default output filename is rcpwave.out

The ray plot data are used to produce wave ray plots of model results using the CMSPOST program RAYPLT (see Appendix C).

f. Enter the name of the output file for ray plot data <ret>
Default output filename for ray plot data is rcpwave.ang

The shoreline data are also used with program RAYPLT:

g. Enter the name of the output file for shoreline data <ret>
Default output filename for shoreline data is rcpwave.shl

The system responds:

```
Request 7280.larry submitted to queue: prime.
**** END OF CMS PROCEDURE
```

This procedure launches a batch job (number 7280) to the CRAY Y-MP.

To execute model CLHYD, the user types:

a. h2crplc1:larry$ /u3/h2crplc0/cms

The CMS responds:

```
W E L C O M E   T O . . .

 XXXXX      X     X      XXXXX
X     X     XX   XX     X     X
X           X X X X     X
X           X  X  X      XXXXX
X           X     X           X
X     X     X     X     X     X
 XXXXX      X     X      XXXXX

        Return for more...
```

```
*********************************************************************
*                        C M S   COMPONENTS                         *
*********************************************************************
*  Options:                                                         *
*                                                                   *
*  CMSGRID (Maps, plots, and lists the numerical grid) -------> 1 *
*                                                                   *
*  CMSMODEL (Compiles, links, loads, and executes                   *
*                numerical models) -------------------------> 2 *
*                                                                   *
*  CMSPOST (Plots and lists model outputs) ------------------> 3 *
*                                                                   *
*  CMSUTIL (Additional "utility" programs) ------------------> 4 *
*                                                                   *
*  Exit CMS ------------------------------------------------> e *
*********************************************************************
```

Enter option number ---------------->

The CMS responds:

```
  CCCCC   M     M    SSSSS   M     M      OO      DDDDD    EEEEE  L
 C        MM   MM   S        MM   MM     O  O     D    D   E      L
C         M M M M   S        M M M M    O    O    D     D  E      L
C         M  M  M    SSSS    M  M  M    O    O    D     D  EEE    L
C         M     M        S   M     M    O    O    D     D  E      L
 C        M     M        S   M     M     O  O     D    D   E      L
  CCCCC   M     M   SSSSS    M     M      OO      DDDDD    EEEEE  LLLLL


                          Return for more. . .
```

```
**********************************************************************
*                                                                    *
*                 USING THE COASTAL MODELING SYSTEM                  *
*                                                                    *
**********************************************************************
*                                                                    *
*  Options:                                                          *
*                                                                    *
*    On-Line Help ------------------------------------------->  1    *
*                                                                    *
*    Enter CMSMODEL Module --------------------------------->  2    *
*                                                                    *
*    Return to Main Menu ----------------------------------->  3    *
*                                                                    *
**********************************************************************
```

Enter option number ----------------> 2

The CMS responds:

```
*************************************************************
*                 Models Presently in System                *
*************************************************************
   CLHYD:     Curvilinear Hydrodynamic 2-Dimensional Model

   RCPWAVE:   Regional Coastal Processes Wave Model

   SPH:       Standard Project Hurricane Wind Model

   WIFM:      WES Implicit Flooding Model

   SWM:       SPECTRAL WAVE MODELING
              SHALWV:  Time Dependent Wave Model
              STWAVE:  Time Independent Wave Model

   EXIT:      Terminate computer session
```

The user is prompted to enter the name of the model desired:

b. Enter name of model clhyd

The CMS responds:

```
  CCCCC    L        H     H     Y     Y    DDDDDD
 C     C   L        H     H      Y   Y     D     D
 C         L        H     H       Y Y      D      D
 C         L        HHHHHHH        Y       D      D
 C         L        H     H        Y       D      D
 C     C   L        H     H        Y       D     D
  CCCCC    LLLLLL   H     H        Y       DDDDDD

                   Return for more...
```

```
Select Model Procedure:

    BUILD - compile and link model
    RUN   - execute model
    EXIT  - terminate computer session
```

For this example CLHYD is executed by responding to the CMS prompt with:

```
c.  Enter procedure name run
```

The user is prompted for the input and output data sets as follows. Note that the names of the user's input and output files may differ from those given in steps d, f, and g. Example input and output files can be found in Chapter 6.

```
d.  Enter name of input data file
    /u3/h2crplcl/vifm/test/indian_nl.inp
```

A hotstart simulation indicates that model results (water surface elevations and velocities) have been saved from a previous simulation and are to be used as initial conditions for the present simulation:

```
e.  Is this a HOTSTART simulation?
    Enter y[es] or n[o] to continue n

f.  Enter the name of the output data file indian.out
```

Hydrograph data are time-histories of model results (i.e., water surface elevations and velocities) at selected (gage) points in the computational domain.

```
g.  Do you want to save hydrographic data?
    Enter y[es] or n[o] to continue y
    Enter the name of the hydrograph data file indian.hyd

h.  Do you wand to save discharge range data?
    Enter y[es] or n[o] to continue  n
```

A snapshot is a "picture" of the flow field for the entire grid or a portion of the grid at a given instant in time.

```
i.  Do you want to save snapshots?
    Enter y[es] or n[o] to continue n
```

The system responds:

```
Request 7528.larry submitted to queue: prime.
**** END OF CMS PROCEDURE
```

This procedure launches a batch job (number 7528) to the CRAY Y-MP.

PART IV: CREATING AND EDITING INPUT FILES TO THE CMS

21. It is recommended that input files to the CMS be created and edited on the VAX 8800 or the user's PC, rather than the CRAY Y-MP. The user will be more familiar with his or her own PC, and in addition, the CRAY editor is known to be cumbersome. The input files can then be transferred to the CRAY Y-MP for use with the CMS (see Part V). An input file for a given model must conform to the specifications outlined in the individual model chapters. For example, model WIFM requires a TIMESPECS card to conform to the following specifications:

```
TIMESPECS      30.  SECONDS       0.  86400.      360.
```

where each variable occupies 8, 16, 24, or 32 columns. It is recommended that the user refer to Chapters 3 through 7 for specific model input requirements. A portion of a WIFM input file is given in Figure 2-1.

```
GENSPECS      WIFM SIMULATION NO. 1:  TIDE WITHOUT FEATHERING
ENGLISH
TIMESPEC     30. SECONDS       0.  86400.    360.
GRIDSPEC         ENGLISH       75      30    500.  1000.       0.      0.0     0.
PRWINDOW                                    3600.                       EV
RECGAGE        19      16        INLET GAGE
RECGAGE        42      15        OCEAN GAGE
XBOUNDRYCONSTELV       75       1      30       1        BDRYX
YBOUNDRYINTRPELV        1      17      75       2       1 BDRY1
YBOUNDRYINTRPELV       30      17      75       2       1 BDRY2
FUNCTION        1HARMCNST
CNRECORD      0.0    1981       6       1     2.5
CONSTIT        M2    3.97  199.02
FUNCTION        2HARMCNST
CNRECORD      0.0    1981       6       1  2.6667
CONSTIT        M2    3.97  199.02
XBARRIER       17      14      14     2.5                XB1
XBARRIER       19      15      15     2.5                XB2
XBARRIER       21      16      16     2.5                XB3
XBARRIER       18      17      17     2.5                XB4
XBARRIER       20      18      18     2.5                XB5
YBARRIER       13      17      17     2.5                YB1
```

Figure 2-1. Sample WIFM input file

PART V: FILE TRANSFER PROCEDURE BETWEEN THE VAX 8800 and CRAY Y-MP

22. When logged onto the VAX 8800, files can be transferred to and from the VAX 8800 as follows:

a. Log onto the VAX 8800

b. Type:

```
ftp larry          <ret>
```

The computer will prompt the user to enter the user's account and password for the CRAY Y-MP.

c. To send a file from the VAX 8800 to the CRAY Y-MP, type in the command:

```
put VAX_file_name CRAY_file_name          <ret>
```

d. To get a file from the CRAY Y-MP and send it to VAX 8800, type in the command:

```
get CRAY_file_name  VAX_file_name          <ret>
```

Note that file transfer is to the main or root directory at the receiving end. If the second filename is omitted, then the filename will remain unchanged on the receiving system.

23. When logged onto the CRAY Y-MP, files can be transferred to and from the CRAY Y-MP as follows:

a. Log onto the CRAY Y-MP

b. Type:

```
ftp wesim3          <ret>
```

The computer will prompt the user to enter the user's account and password for the VAX 8800.

c. To send a file from the CRAY Y-MP to the VAX 8800, type in the command:

```
put CRAY_file_name  VAX_file_name          <ret>
```

d. To get a file from the VAX 8800 to the CRAY Y-MP, type in the command:

```
get VAX_file_name   CRAY_file_name          <ret>
```

CHAPTER 3

STANDARD PROJECT HURRICANE (SPH) MODEL

THEORY AND PROGRAM DOCUMENTATION

PART I: INTRODUCTION

1. Planning and design of coastal structures may require a storm surge analysis to obtain a design water level. Statistical methods, where the design water level is obtained through analyzing historical water surface elevation records, can rarely be applied because of the infrequent occurrence of hurricanes at a given site. Hence, numerical computational methods are often used to simulate storm surge events. This chapter documents the Standard Project Hurricane (SPH) wind-field model for calculating wind velocity and atmospheric pressure fields generated by hurricanes. This information can be used by a hydrodynamic model to determine the design water level.

2. Model SPH is one of several models the Coastal Engineering Research Center (CERC) uses for performing storm surge studies. This model's function is to generate wind velocity and atmospheric pressure fields for subsequent use by the hydrodynamic model WIFM. Furthermore, model SPH is structured so that it can be used as an independent model, or as an integrated component of model WIFM.

3. Model SPH was developed from the meteorological criteria adopted by the National Oceanic and Atmospheric Administration (NOAA) (1979) for the Gulf of Mexico and East Coast of the United States. The SPH represents a steady-state, hypothetical hurricane defined by the following set of interrelated parameters:

a. Longitude and latitude at the low-pressure center, or eye of a hurricane.

b. Central pressure, or atmospheric pressure measured at the eye of a hurricane.

c. Peripheral pressure, or atmospheric pressure at the edge of a hurricane.

d. Track angle, measured clockwise from north, defining the direction in which a hurricane is traveling.

e. Translational speed, or forward speed of a hurricane.

f. Inflow angle of winds, accounting for the inward spiraling of horizontal wind velocities about the hurricane center measured

between a line tangent to an iso-velocity circle and the associated inflow wind velocity vector.

g. Radius to maximum winds, measured from the eye of a hurricane to the iso-velocity circle of maximum wind velocities.

h. Maximum wind speed, either defined explicitly or calculated from the difference between central and ambient pressures.

i. Radial decay factor, defining the decrease in wind speed with increasing radial distance outward from the radius to maximum winds.

j. Azimuth angle to the maximum velocity vector.

4. According to the NOAA definition, the Standard Project Hurricane represents the most severe hurricane, excluding extremely rare events, producing the highest sustained wind speeds for a specific region. Due to uncertainties involved in establishing frequency parameters, the NOAA does not assign a frequency of occurrence to a Standard Project Hurricane. Parameter values, established through a statistical analysis of historical hurricane events, are presented in this chapter.

5. Model SPH was originally developed for simulating a steady-state, hypothetical Standard Project Hurricane; however, features have been added to this model for replicating historical hurricane events. Because this model's governing equations were developed from those hurricanes contained in NOAA's statistical data set, this model may not be ideally suited for simulating individual historical events. When possible, the user should compare model results against field data to determine whether this model accurately computes the wind velocity and atmospheric pressure fields produced by historical storms in a given study area.

6. This chapter is organized into six sections: Part II presents the development of the governing equations and computational scheme used in the model; Part III presents the parameters for describing SPH and historical storms; Part IV discusses the model's input data requirements; Part V defines the input data formats; and Part VI contains two illustrative examples.

PART II: COMPUTATIONAL TECHNIQUE

7. Hurricane wind fields are characterized by high winds blowing spirally inward toward a low-pressure center. For hurricanes occurring in the Northern Hemisphere, wind fields rotate in a counterclockwise direction. Relatively low wind speeds are experienced at the hurricane's center and rapidly increase to speeds exceeding 75 knots* at a radial distance that generally ranges from 4 to 60 n.m. Wind speeds gradually diminish beyond this point as the radial distance extends towards the storm's periphery. Atmospheric pressures are lowest at the storm's center and slowly increase towards the storm's edge.

8. Although winds in an actual hurricane do not necessarily rotate in concentric circles, development of the equation for computing a hurricane's maximum theoretical rotational wind speed assumes a stationary storm where winds blow under gradient wind conditions. These conditions are defined as winds blowing in a circular motion parallel to the storm's isobars, such that the wind's centripetal and coriolis acceleration forces balance the horizontal pressure gradient force. Gradient wind conditions can be mathematically expressed as:

$$\frac{V_g^2}{r} + fV_g = \frac{1}{\rho_a}\frac{dP}{dr} \tag{3-1}$$

where

V_g - gradient wind velocity

r - radial distance measured from the hurricane center

f - coriolis acceleration parameter

ρ_a - air density

P - atmospheric pressure

9. NOAA (1979) found that when hurricanes occur at low latitudes and have small radii to maximum winds, the maximum wind speeds are approximately in cyclostrophic balance. This means that the wind's centripetal acceleration approximately equals the horizontal pressure gradient:

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page vii.

$$8\frac{V_c^2}{r} = \frac{1}{\rho_a}\frac{dP}{dr} \qquad (3\text{-}2)$$

where V_c is the cyclostrophic wind velocity.

10. Equating Equations 3-1 and 3-2 yields:

$$\frac{V_g^2}{r} + fV_g = \frac{V_c^2}{r} \qquad (3\text{-}3)$$

or

$$V_g - V_c = \frac{-rfV_g}{V_g + V_c} \qquad (3\text{-}4)$$

11. For the range of wind speeds used in hurricane studies, the difference between the quantities V_c and V_g is small in comparison to the quantities themselves. Therefore, the following approximation is valid:

$$V_g - V_c = \frac{-rf}{2} \qquad (3\text{-}5)$$

12. Schloemer (1954) developed an empirical formula for approximating a hurricane's horizontal pressure distribution:

$$\frac{P - P_o}{P_\infty - P_o} = e^{-R/r} \qquad (3\text{-}6)$$

or

$$\frac{dP}{dr} = \frac{(P_\infty - P_o)}{r^2} Re^{-R/r} \qquad (3\text{-}7)$$

where

P = atmospheric pressure at any location

P_o = atmospheric pressure at the eye of the hurricane

P_∞ = atmospheric pressure at the periphery

R = radial distance from the hurricane center to the location of maximum rotational wind speed

13. Expressing the cyclostrophic wind speed in terms of the horizontal pressure distribution yields:

$$V_c = \left[\frac{P_\infty - P_o}{\rho_a r} Re^{-R/r} \right]^{1/2} \qquad (3\text{-}8)$$

14. Substituting Equation 3-8 into 3-5 and evaluating the resulting equation at the radius to maximum winds, the maximum theoretical gradient wind speed is:

$$V_{gx} = K[P_\infty - P_o]^{1/2} - \frac{Rf}{2} \qquad (3\text{-}9)$$

where V_{gx} is the maximum theoretical gradient wind speed, and K is a coefficient accounting for air density at the air-sea interface.

15. Myers (1954) observed that the maximum theoretical gradient wind speeds predicted by Equation 3-9 overestimate the maximum rotational wind speeds produced by historical, stationary hurricanes in open water by as much as 25 percent. To rectify this problem, NOAA (1979) adopted a multiplicative correction factor of 0.90 to adjust a hurricane's maximum theoretical gradient wind speed to obtain the maximum rotational wind speed:

$$V_{xs} = 0.90\, V_{gx} \qquad (3\text{-}10)$$

where V_{xs} is the maximum rotational wind speed for a stationary hurricane.

16. A hurricane's radial wind distribution is categorized into three zones (Figure 3-1). The first zone extends from its center outward to a distance that is 80 percent of the radius to maximum winds (R_1). In this zone, wind speeds are assumed to increase linearly from zero at the center, to the maximum rotational wind speed at this zone's outer radial limit. The second zone, where wind speeds are assumed equal to the maximum wind speeds, extends for the first zone's outer limit to a distance equal to 120 percent of the radius to maximum winds (R_u). Wind speeds in the third zone, extending outward from the second zone's outer limit, decay exponentially as the radial distance approaches the storm's edge.

17. To reproduce this distribution, model SPH employs the following wind distribution function:

$$f(r) = \begin{cases} r/R_1 & for\ r < R_1 \\ 1 & for\ R_1 \le r < R_u \\ F_N(R_e, R) & for\ r \ge R_u \end{cases} \qquad (3\text{-}11)$$

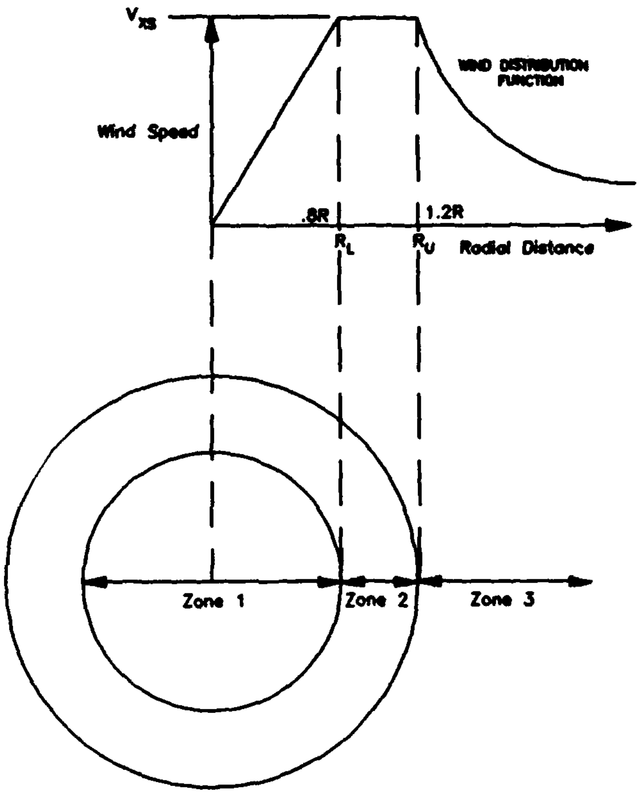


Figure 3-1. Radial wind distribution

where

$f(r)$	=	velocity distribution function
R	=	radius to maximum winds
R_e	=	effective radius parameter
$F_N(R_e,R)$	=	radial velocity reduction function originally presented by NOAA (1979) in nomograph form

Applying a power law and a least-squares regression analysis, the nomograph can be mathematically described as:

$$F_N(R_e, R) = a_1 e^{-r^*/b_1} + a_2 e^{-r^*/b_2} \tag{3-12}$$

where

$$r^* = \frac{(r - R_u)}{R}$$

$$a_1 = 1 - a_2 \qquad b_1 = 45R_e^{-0.500}$$
$$a_2 = 0.33R_e^{-0.12} \qquad b_2 = 3.4R_e^{-0.306}$$

Multiplying the maximum rotational wind speed presented in Equation 3-10 with the wind distribution function, the wind velocities at any radial distance, V_s , can be computed by:

$$V_s = f(r)\,V_{xs} \tag{3-13}$$

18. These equations were developed assuming a stationary hurricane whose wind velocity field is symmetric about its center (i.e., wind velocity, while dependent in the radial direction, is independent of the angular direction). Forward motion by a hurricane induces an asymmetric wind-field distribution where the total wind velocity vectors (rotational component added to the forward translational component) are greater in the hurricane's right hemisphere (relative to the storm's direction) than in its left for hurricanes occurring in the Northern Hemisphere. Hence, the maximum wind velocity occurs at a point along the circumference of maximum winds where the rotational wind velocity vector is parallel to the forward velocity vector (Figure 3-2).

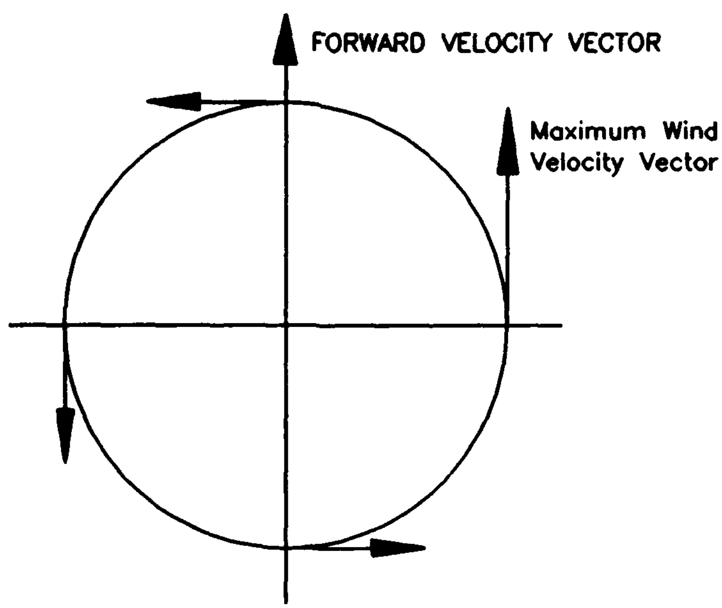


Figure 3-2. Total wind velocity vectors

19. Assuming that a hurricane's forward speed is incorporated into Equation 3-13, the total wind velocity at any location within the hurricane can be computed by:

$$V = f(r)\, V_{xs} - \frac{1}{2} S_f (1 - \cos\beta) \tag{3-14}$$

where V_{xs} is the maximum wind velocity, S_f is the forward speed, and β is the angle formed by the forward velocity vector and the rotational wind velocity vector (Figure 3-3). This angle is measured in a counterclockwise direction from the forward velocity vector. Thus, the maximum wind speed will occur at the point along the circumference of maximum wind speeds where β is equal to zero.

20. However, one must also consider the inflow angle, α, (Figure 3-4). The inflow angle accounts for the spiral horizontal wind velocities about the hurricane center and is the angle measured between the rotational velocity vector and the inflow velocity vector. Although this angle varies with radial distance in actual hurricanes, it is assumed constant in model SPH. As shown in Figure 3-4, the maximum wind speed occurs where the inflow velocity vector is parallel to the forward velocity vector. Typically, this point is in a hurricane's right-rear quadrant where the azimuth angle, θ, ranges from 90 to 180 deg.

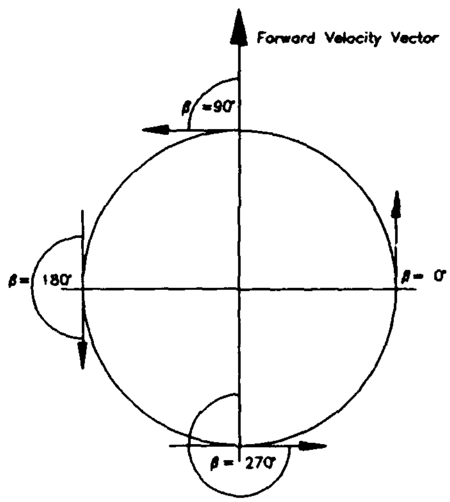


Figure 3-3. Definition sketch for angle to rotational wind velocity vector, β

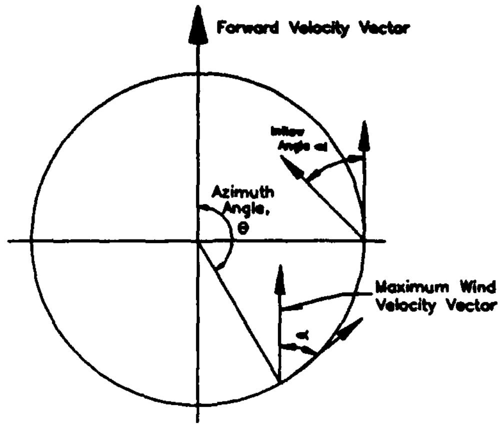


Figure 3-4. Definition sketch of inflow angle, α

21. Equations 3-7 and 3-13 have been defined relative to the hurricane center. In the model, the locations where the wind velocity and atmospheric pressure fields are evaluated are defined by a computational grid composed of a lattice network of cells. Wind velocities and atmospheric pressures are computed at the center of each cell. Distances and angles from the center of a grid cell to the eye of the hurricane are computed relative to the grid origin by the following relationships:

$$r = [(x_i - x_h)^2 + (y_j - y_h)^2]^{1/2} \tag{3-15}$$

$$\phi = \arctan\left(\frac{y_j - y_h}{x_i - x_h}\right) \tag{3-16}$$

where

r = distance

ϕ = angle

(x_i, y_j), (x_h, y_h) = grid cell and hurricane eye coordinates, respectively (Figure 3-5)

22. The atmospheric pressure anomaly is computed at each cell by:

$$\Delta P = \frac{P_\infty - P_o}{\gamma}(1 - e^{-R/r}) \tag{3-17}$$

where

ΔP - pressure head anomaly

P_o - central pressure

P_∞ - peripheral pressure

γ - specific weight of water

r - radial distance

R - radius from the eye to the maximum winds

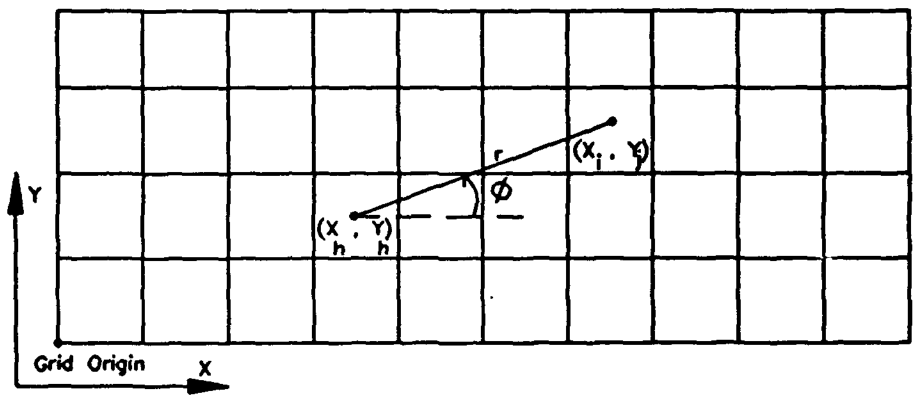


Figure 3-5. Distance and angle from the eye of a hurricane to a grid cell

23. The x- and y-direction wind velocities are computed at each cell center by:

$$W_x = [f(r)\,V_{xs} - \frac{1}{2}S_f(1-\cos\beta)]\sin(\phi+\alpha) \tag{3-18}$$

$$W_y = [f(r)\,V_{xs} - \frac{1}{2}S_f(1-\cos\beta)]\cos(\phi+\alpha) \tag{3-19}$$

where W_x and W_y are the x- and y-direction wind velocity components, respectively.

24. As a hurricane travels towards the coastline, the leading edge of its wind field moves overland, and eventually the eye of the storm makes landfall. The rough character of the land in comparison to the water causes a reduction in the wind speed. Further weakening of the wind field takes place

when the eye moves ashore. The storm's energy is reduced because the surface air is no longer warmed by the ocean. The wind velocities are adjusted for overland effects as follows: an overland reduction factor due to the wind strength is computed as:

$$O_f = \begin{cases} 0.78 & \textit{for } v \le 73 \textit{ knots} \\ 0.40 + \dfrac{0.38(V-10)}{63} & \textit{for } 10 < V < 73 \textit{ knots} \\ 0.40 & \textit{for } V \le 10 \textit{ knots} \end{cases} \tag{3-20}$$

The wind components W_x and W_y are then given by:

$$W_x = W_x(1 - R_f(1 - O_f)) \tag{3-21}$$

$$W_y = W_y(1 - R_f(1 - O_f)) \tag{3-22}$$

where R_f is a reduction coefficient that accounts for the fetch length.

PART III: DETERMINATION OF HURRICANE PARAMETERS

Parameters for the SPH

25. One use of model SPH is for calculating the meteorology (winds and pressures) associated with the SPH for a particular stretch of coastline. Reiterating, the SPH represents the most severe hurricane, excluding extremely rare events, producing the highest sustained wind speeds for a specific region. The meteorological parameters necessary to compute SPH wind fields are referenced relative to the latitude of the study site and coastline distance to the site measured relative to the United States-Mexico border (Figure 3-6). Coastline distances in Figure 3-6 are given in nautical miles and kilometers. Figures 3-6 through 3-12 and 3-14 are from NOAA Technical Report No. 23 "Meteorological Criteria for Standard Project Hurricane and Probable Maximum Hurricane Wind Fields, Gulf and East Coasts of the United States". The SPH parameters are determined in the following manner:

a. Peripheral pressure is equal to 29.77 in. Hg in allapplications.

b. Central pressure index is selected from Figure 3-7.

c. Forward speed is chosen from Figure 3-8.

d. Radius to maximum winds is selected from Figure 3-9.

e. Wind inflow, or ingress angle, is chosen from Figure 3-10.

f. Track angle (measured clockwise from north), for which a range of permissible values are given, is selected using Figure 3-11 and Table 3-1.

Parameters selected from figures and tables for forward speed, radius to maximum winds, and track direction contain a range of suitable values. Choosing the maximum value for each particular parameter does not guarantee that the predicted wind fields will generate the maximum storm surge level. This value is not only a function of the hurricane's intensity, but also a study area's hydraulic features, including bathymetric gradients, inlet configurations, and channel depths. Several parameter combinations must be tested when performing a storm surge analysis to ensure that the maximum storm surge level has been obtained.

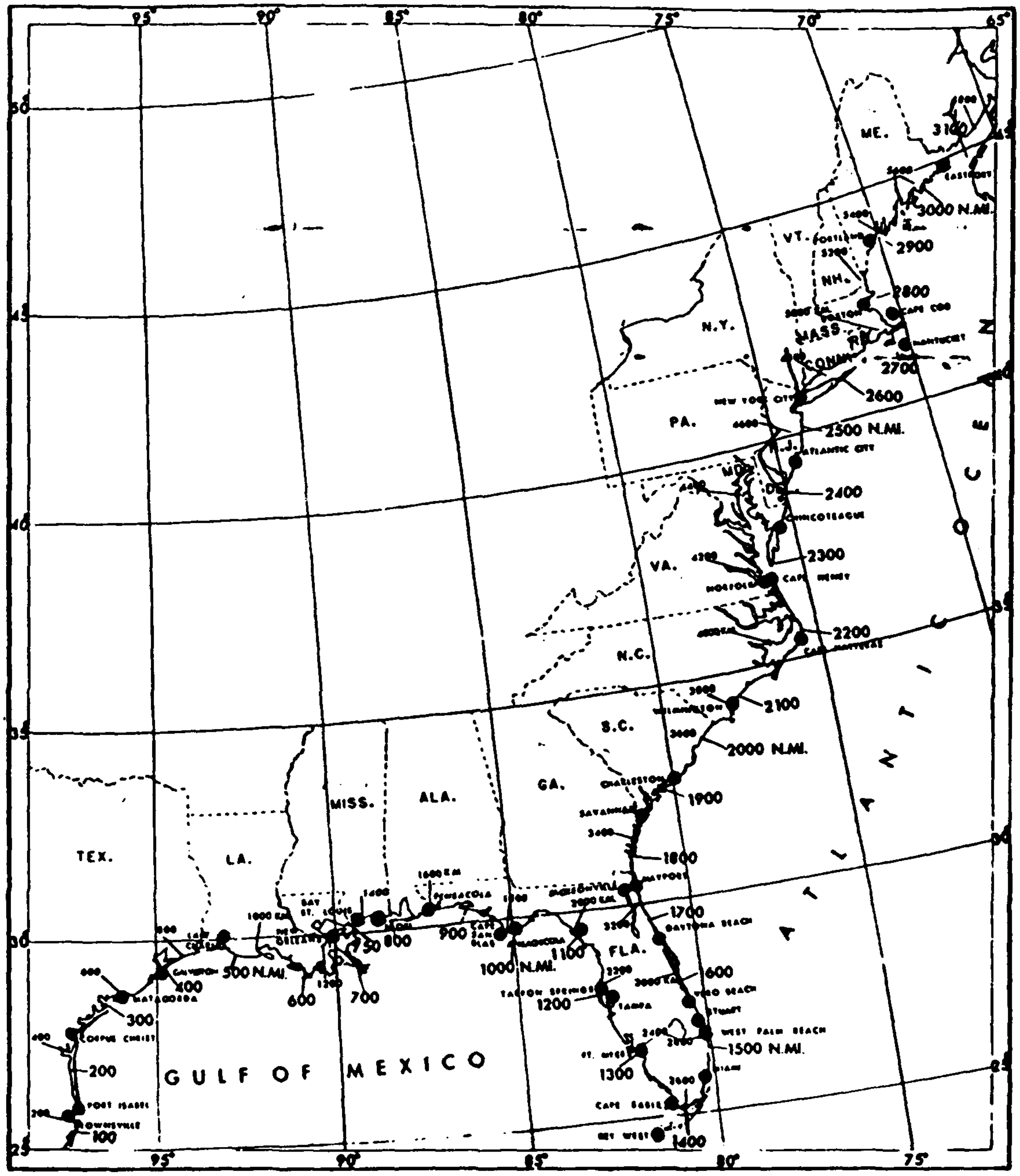


Figure 3-6. Location map with coastal distance intervals marked in nautical miles and kilometers (from NOAA Technical Report NWS 23)

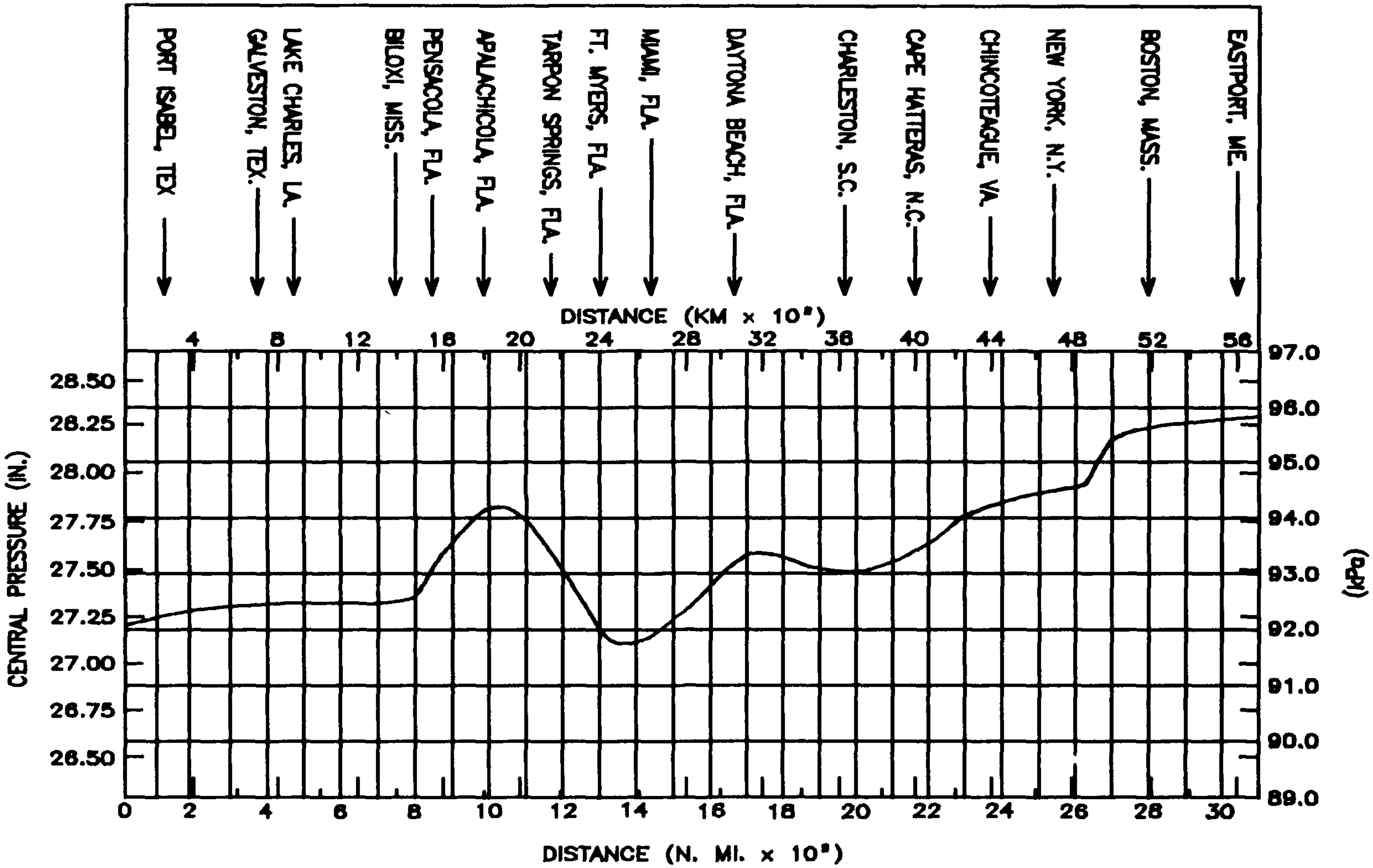


Figure 3-7. Central pressure index versus distance form the United States-Mexico border (from NOAA Technical Report NWS 23)

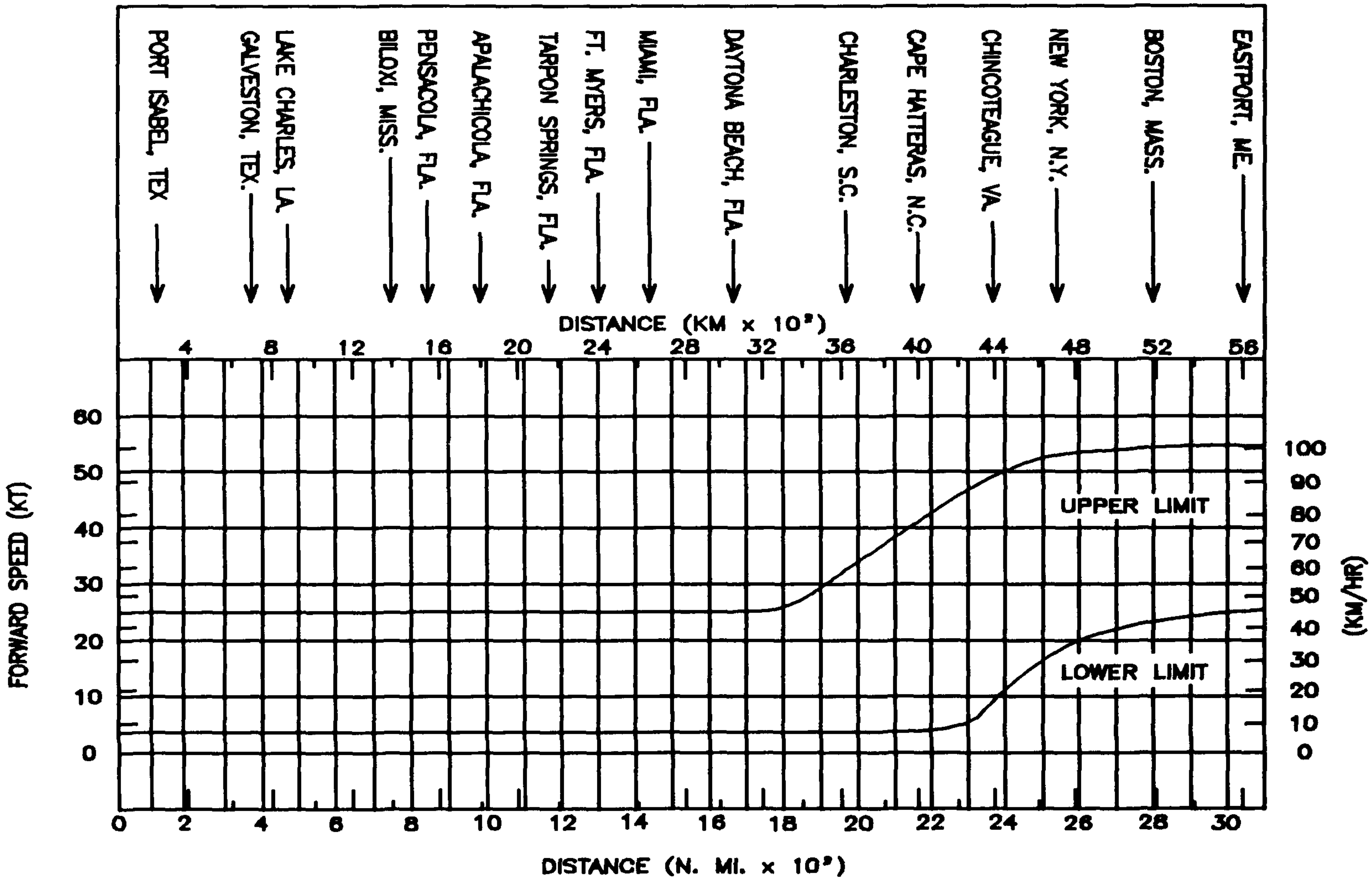


Figure 3-8. SPH upper and lower limits of S_f (from NOAA Technical Report NWS 23)

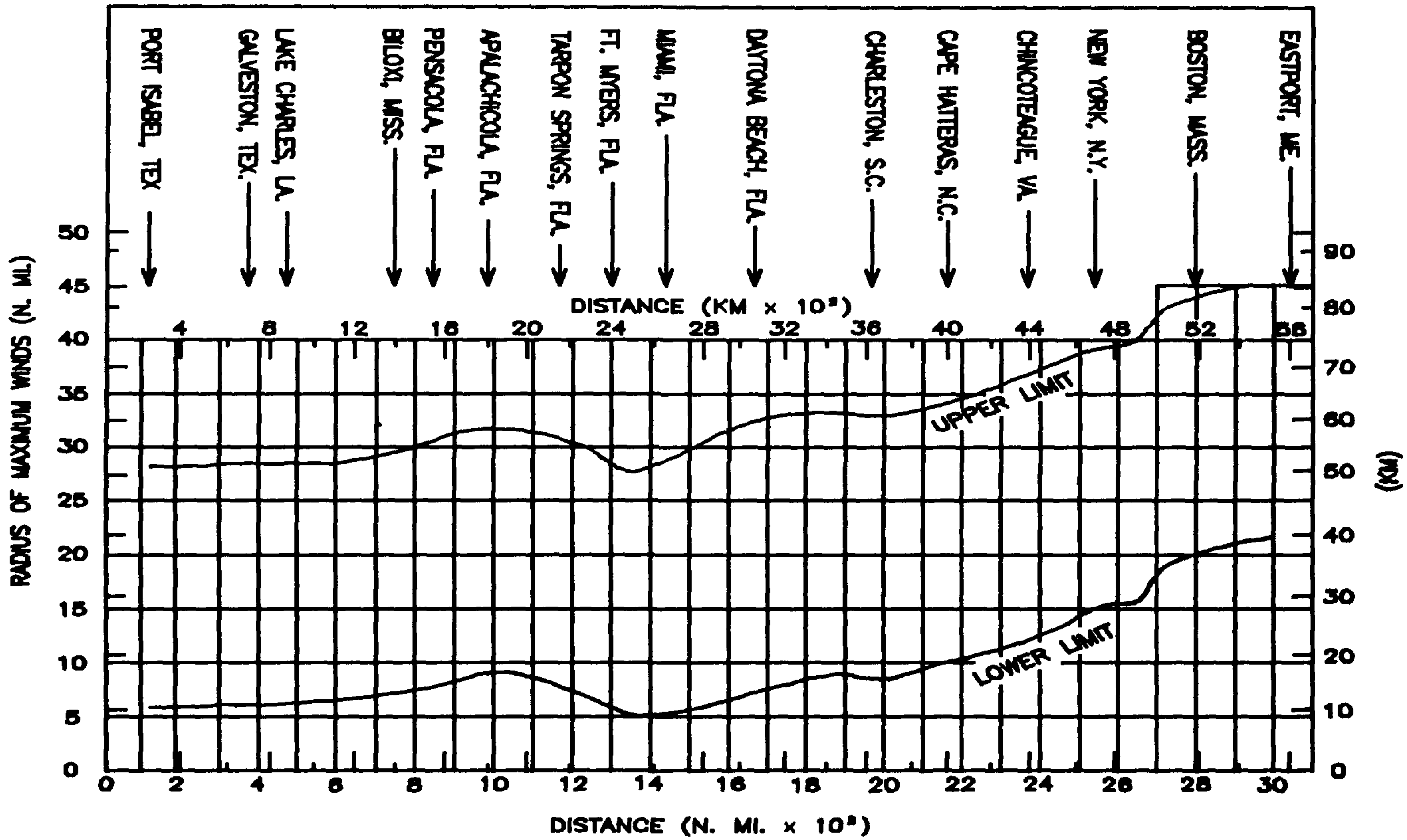


Figure 3-9. Upper and lower limits of radius to maximum winds for the SPH (from NOAA Technical Report NWS 23)

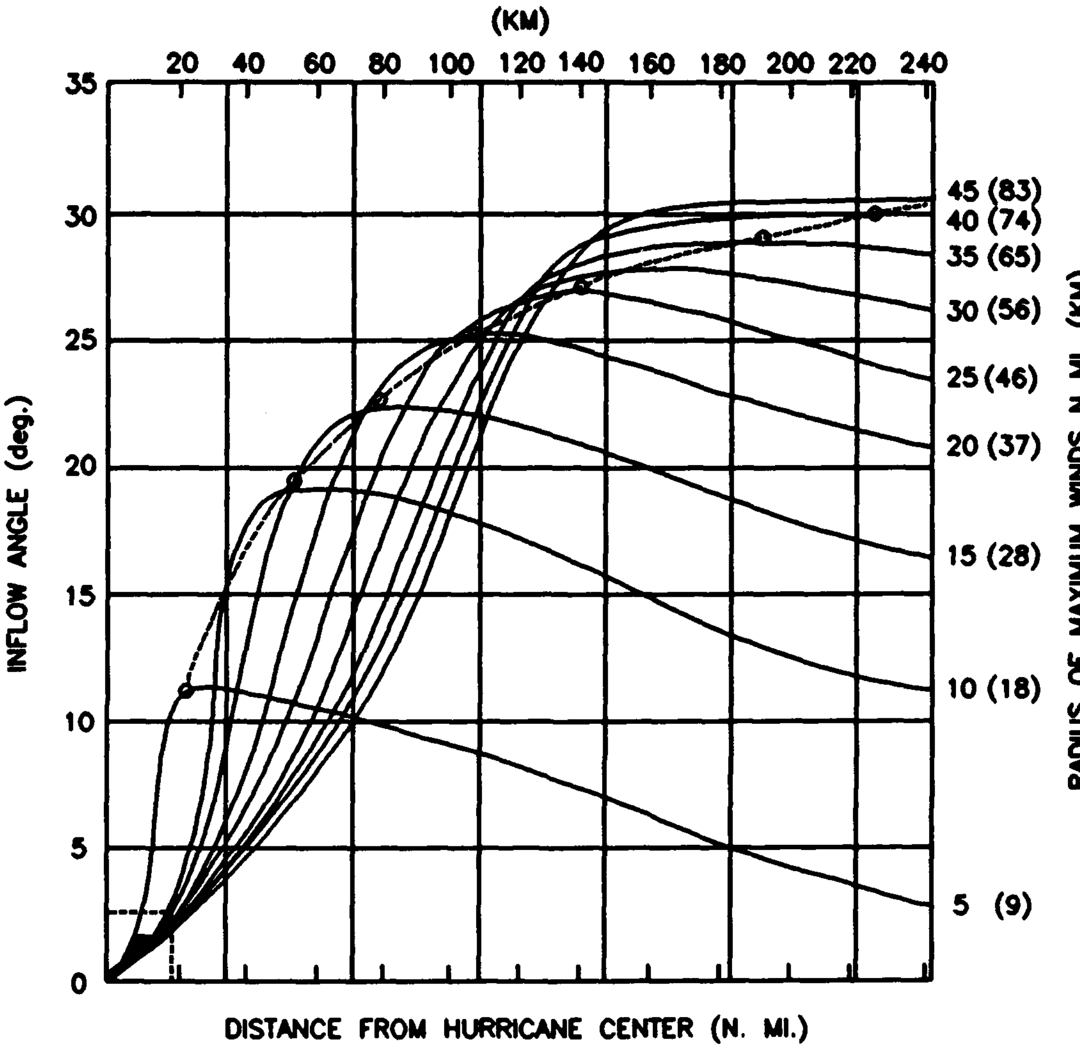


Figure 3-10. Adopted SPH inflow angles versus distance from the hurricane center at selected *R* values. Open circles denote maximum inflow angle at each *R* (from NOAA Technical Report NWS 23)

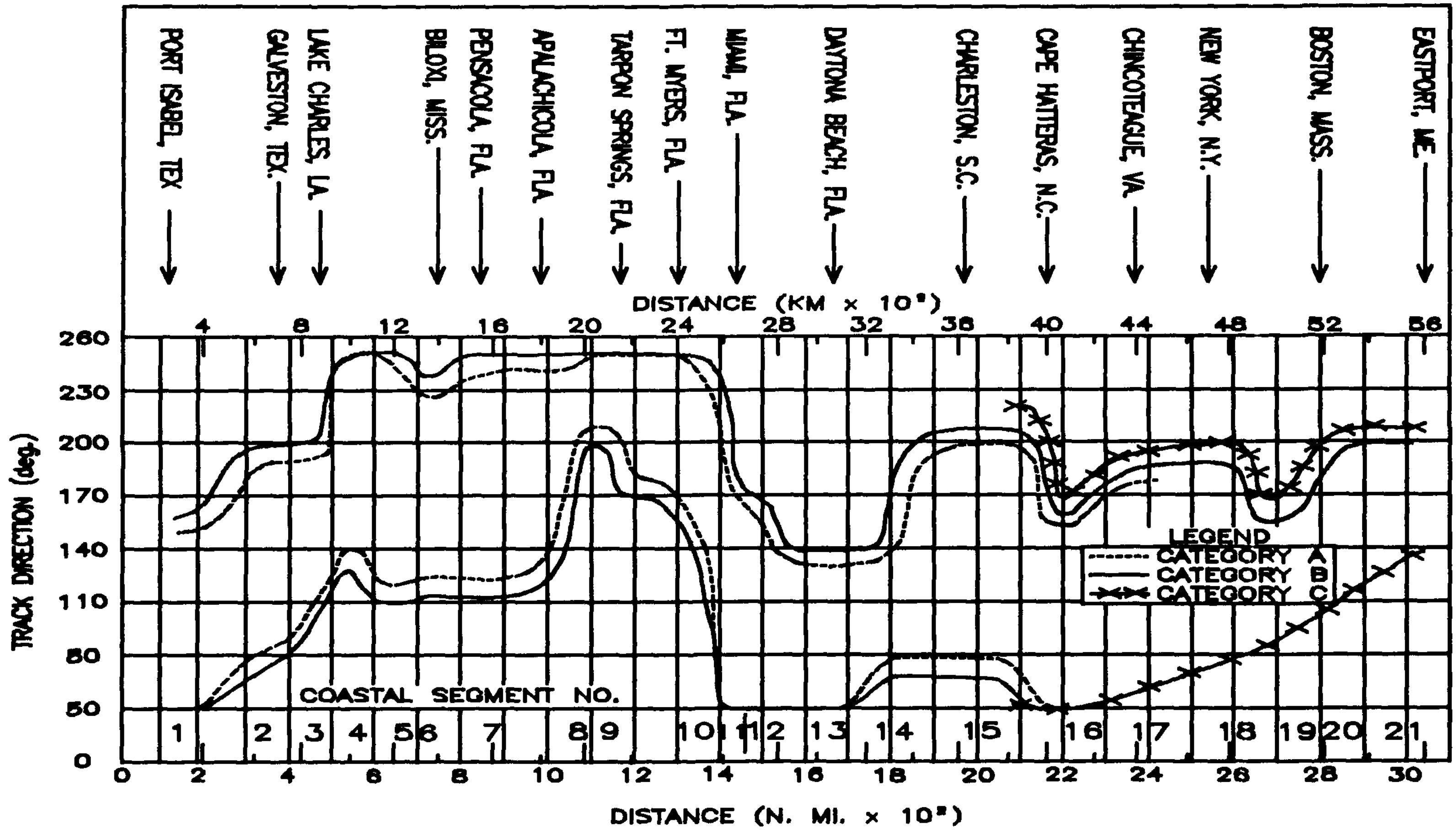


Figure 3-11. Maximum allowable range of SPH θ (from NOAA Technical Report NWS 23)

Table 3-1

Speed Category as a Function of Forward Speed

Speed Category	Forward Speed knots
A	$6.0 \leq S_f < 10.0$
B	$10.0 \leq S_f < 36.0$
C	$36.0 \leq S_f$

26. Maximum rotational wind speed is computed by:

$$V_{xs} = 0.90\left[K(P_\infty - P_o)^{1/2} - \frac{Rf}{2}\right] \tag{3-23}$$

where

V_{xs} = maximum wind speed

K = coefficient accounting for air density dependency on the latitude of the study site

P_∞ = atmospheric pressure at the periphery

P_o = atmospheric pressure at the eye of the hurricane

R = radius to maximum wind velocities

f = coriolis parameter

Coefficient K is selected from Figure 3-12. The coriolis parameter is computed by:

$$f = 2\omega\sin(\lambda) \tag{3-24}$$

where ω is the earth's angular velocity (equal to 0.262 rad/hr) and λ is the latitude of the study site.

27. The angle to maximum winds or azimuth angle, θ , is the angle formed by the forward velocity vector (i.e., the direction in which the hurricane is traveling) and a radii extending from the eye of the hurricane to the location of maximum wind speed (Figure 3-13). The maximum wind speed incorporates the forward and rotational wind velocities, including inflow

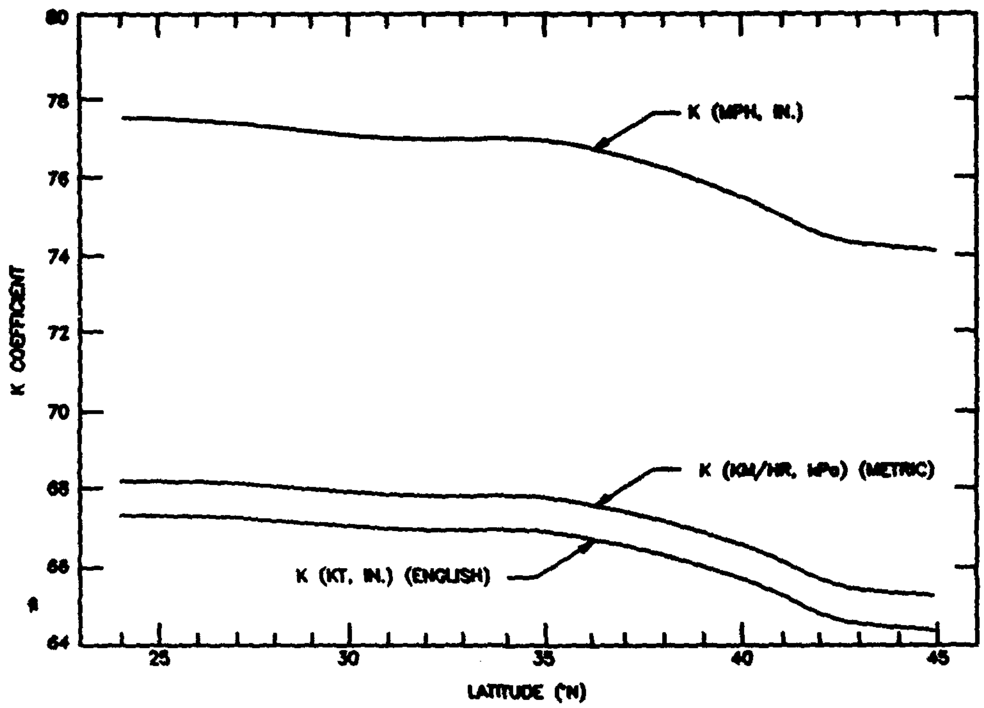


Figure 3-12. Values of the latitude-independent K coefficient for three units of measurement for the SPH (from NOAA Technical Report NWS 23)

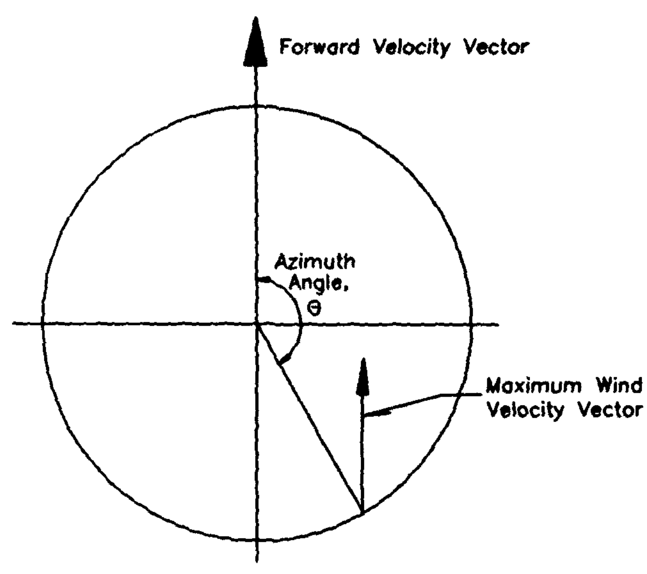


Figure 3-13. Definition sketch for angle to maximum winds

effects. This angle is normally between 90 and 180 deg measured in a clockwise direction from the forward velocity vector.

28. The effective radius parameter is a scaling, or form factor, that adjusts the radial wind velocity distribution in the region between the zone of maximum winds and the storm's periphery. This parameter is set equal to the radius to maximum winds for the SPH.

Parameters for Historical Storms

29. Model SPH can be used for computing the meteorology (winds and pressures) associated with a historical storm. Certain storm parameters which describe the hurricane must be specified as a function of time. Model SPH can then compute the wind and atmospheric pressure fields at user specified times. For a historical hurricane, the storm's movement is tracked by the position of its eye, rather than its forward speed and track angle. Values for the peripheral pressure, central pressure, radius to maximum winds, maximum wind speed, azimuth angle, and inflow angle should be known or estimated as input to the model. The user should also search for data describing the wind-field distribution outside the maximum wind band. To compute the effective radius parameter the user should:

- a. Compute and plot the relative wind speed (the ratio of wind speed to over-water maximum wind speed) for several radii beyond the radius to maximum winds.

- b. Compare the curve developed in item (a) to the nomographs presented in Figure 3-14.

- c. Select an effective radius parameter corresponding to the value given for the curve on the nomograph that most closely resembles the historical wind-field distribution.

Figure 3-14 presents the far-field radial wind distribution for selected values of the parameter radius to maximum winds. Radial distances presented along the figure's x-axis are measured relative to the hurricane's center. Furthermore, each nomograph assumes a stationary hurricane. Thus, asymmetric effects induced by a storm's forward motion must be eliminated before comparing historical data to this figure.

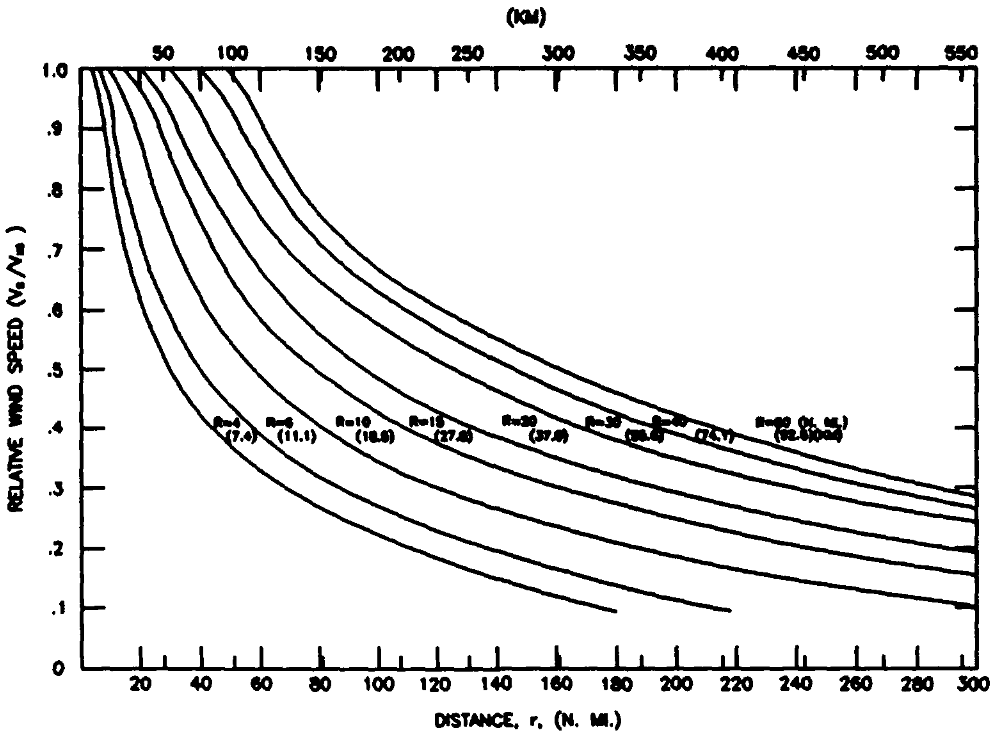


Figure 3-14. Standardized wind profiles outward from R for the stationary SPH (from NOAA Technical Report NWS 23)

PART IV: DISCUSSION OF INPUT DATA REQUIREMENTS

30. The structure of model SPH allows it to be used as an independent or "stand-alone" model, or as a component of the hydrodynamic model WIFM. WIFM (see Chapter 4) shares those subroutines in model SPH that compute hurricane wind and pressure anomaly fields, and model SPH can therefore be executed within the context of a WIFM simulation. This feature saves labor and computer costs associated with running model SPH independently to generate wind fields for WIFM applications. For a stand-alone application, the discussion of input data requirements are divided into five categories:

- a. Model control specifications.
- b. Grid description.
- c. Physical characteristics.
- d. Wind-field specifications.
- e. Output specifications.

29. For applying model SPH as a component of WIFM, the user should review item (d) and the input data requirements for WIFM. Wind-field input data are identical for both models. Table 3-2 presents model SPH input data records pertaining to each category. (A record refers to one line of data, and each record begins with a mnemonic character string to identify one record type from another.) Record format and detailed descriptions of input data entered on each record are provided in Part V. While reading Part IV, the user will find it beneficial to refer to Appendix 3-A.

Model Control Specifications

31. Model control data records include GENSPECS and TIMESPEC. Record GENSPECS is used for specifying the general title of the simulation (TITLE) and the system of units (SUNITS) for displaying model results. Variable names are given in parentheses. In addition to the general title, other input data records have provision for titles. Although this information is optional, it can be very helpful when reviewing a series of simulations. A title should specifically state data set attributes to distinguish one simulation from another.

Table 3-2

Input Data Set Records

Category	Record Name
Model control specifications	GENSPECS TIMESPEC
Grid description	GRIDSPEC XSTRETCH YSTRETCH
Physical characteristics	BATHSPEC CHNGBATH
Wind-field specifications	WINDSPEC SPHSPEC TABSPH
Output specifications	PRWINDOW RECGAGE RECSNAPS

32. Model output is presented in either British or SI units. However, the user can specify a different system of units for the input data. For example, the user can supply wind velocity data in units of either miles-per-hour, feet-per-second, meters-per-second, or knots. Model SPH will perform the necessary conversion to place the input data into the system of units used for computations.

33. Record TIMESPEC controls the processing of all time-related variables. Variable DELT defines the time-step or time interval when wind-field data may be saved for use by a hydrodynamic model and must have units of seconds. DELT is also the time-step used by WIFM and is generally smaller than the time-step required for SPH model computations (SPHDLT). Variable TUNITS controls the units of <u>all</u> <u>other</u> time-dependent variables (e.g., DTGAGS). Valid time units are hours, minutes, and seconds.

34. Variable TPROV defines the provisional model time at the start of the simulation, and variable TMAX controls the simulation's duration. Typically, a hurricane simulation begins at time 0.0 and has a duration exceeding 24 hr. This duration provides a hydrodynamic model sufficient time

in which to develop accurate circulation fields and avoids the generation of numerical instabilities induced by instantaneously applying high wind velocities to a static water basin.

35. Variable DTGAGS specifies the frequency at which numerical gage time-history data (i.e., wind velocities and atmospheric pressures) are saved for future processing by the post-processing package in the Coastal Modeling System (CMS). Quantities assigned to this variable must be an integer multiple of the time-step variable DELT. Numerical gage locations (locations for which time-histories are saved) are selected with the RECGAGES record, which is discussed in the model output specification section.

Grid Description

36. The study area is defined in the model via a computational grid. The grid is composed of rectilinear cells, where each cell is assigned a two-dimensional index. The first index (i) corresponds to the x-coordinate and the second index (j) corresponds to the y-coordinate. The grid index system is presented in Figure 3-15. All wind-field and atmospheric pressure data are assigned and referenced to their respective grid cells with this system.

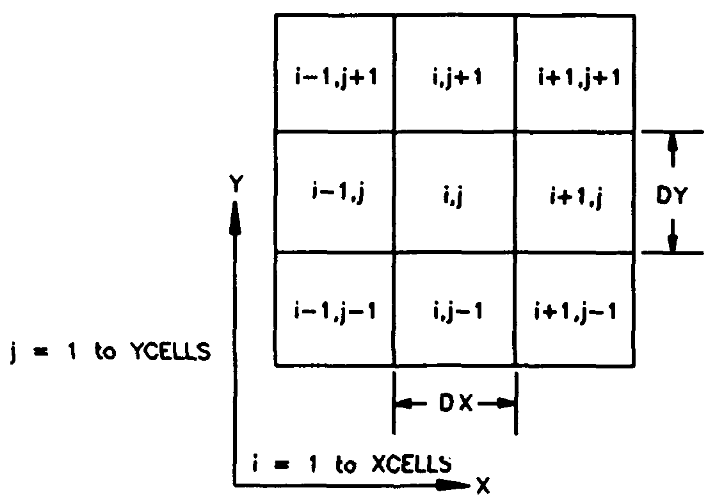


Figure 3-15. Definition of coordinate system and grid cell convention

37. Model SPH permits a rectilinear stretched grid coordinate system, where successive grid cells can have smoothly varying widths. Grids with uniform cell widths are also permitted. Procedures for constructing a grid are presented in documentation of package CMSGRID (Appendix A of this manual). CMSGRID guidelines for grid generation pertain to hydrodynamic models. If model SPH is intended to supply wind-field data to a hydrodynamic model, the grids for model SPH and the hydrodynamic models must be identical. CMS does not have the capability to interpolate wind-field data from one rectilinear grid to another or from one grid type to another. If model SPH output data are not intended for input into a hydrodynamic model, the grid cell size restrictions can be relaxed (i.e., larger cell sizes, on the order of 1mile, are allowed). Guidelines for overall grid dimensions and grid alignment are the same for model SPH as for WIFM. Sufficient detail of landform/bathymetry must be provided for accurate calculation of wind fields influenced by over-land friction effects.

38. Selection of grid coordinate systems is controlled by variable GRTYPE on record GRIDSPEC. A uniform, or constant, grid cell size is selected by assigning the character string RECTANG to variable GRTYPE, whereas string RSTRETCH selects a stretched rectilinear grid. If the stretched grid option is selected, record GRIDSPEC must be followed by a set of XSTRETCH and YSTRETCH records (Table 3-3). These records are generated by the interactive grid generation program MAPIT contained in package CMSGRID and can be placed directly into the input data set without modification. The reader can refer to Appendix A for more information on XSTRETCH and YSTRETCH.

39. Variable GUNITS on record GRIDSPEC controls the system of units for the computational grid. Valid units are ENGLISH or METRIC. Model SPH will convert the data to the system of units for computations (SUNITS) internally. Variables XCELLS and YCELLS specify the number of grid cells in the x- and y-direction, respectively. Variables DX and DY on record GRIDSPEC specify a grid's spatial mapping scale in the x- and y-directions, respectively. For uniform grid cells, these variables are assigned the physical width of a single cell. For stretched rectilinear grids, the variables DX and DY are assigned the value 1.0 if physical distances were used in generating the grid. The variables DX and DY are assigned the value of the map scale if relative map distances were used in generating the grid. As an example, a map with a scale of 1:10,000 is used to generate a stretched rectangular grid. If the

physical distances (i.e., grid distances on the 10,000-ft scale) are used to generate the mapping coefficients, then DX and DY are 1.0 because no conversion of units is necessary. However, if the map distances (i.e., grid distances measured in map inches) are used to generate the mapping coefficients, then DX and DY are 120,000 to convert map inches to physical distances (in feet).

40. Variables GLATT and GLONG specify the latitude and longitude of the grid origin in decimal degrees, respectively. GALIGN specifies the counterclockwise rotation of the x-axis from due east (in decimal degrees).

Table 3-3

Sample XSTRETCH and YSTRETCH Records

XSTRETCH	1	4	-.696333695	.696333695	.933460501
XSTRETCH	4	9	-6.69031772	5.80606023	.277821490
XSTRETCH	9	19	.143110486	.710267924	.770050578
YSTRETCH	1	17	-.500000000	.500000000	1.00000000

Physical Characteristics

41. Each grid cell must be assigned a water depth or land elevation. Topography/bathymetry data are referenced relative to an arbitrary datum. Typically, the map datum from which the depths are taken is used. Water cells are designated by negative values and land cells have positive values.

42. One BATHSPEC record is required for defining the general characteristics of the topography/bathymetry array and must precede this array. Variable BUNITS defines the units of topography/bathymetry data. Valid units are feet, meters, or fathoms. The input sequence for reading this array is controlled by variable BSEQ. Eight options for the input sequence are available for reading the array data and are given in Table 3-4. For the first input sequence (Figure 3-16), the depths are read along the x-direction, then y is incremented to a value 2, and again the sweep in the x-direction takes place. This procedure is repeated until the entire array of data is read. The input format for reading this array can be selected by the user with variable BFORM.

Table 3-4

Input Sequence for Array Data

No	Sequence	Description
1	XY	DO 1 J=1,YCELLS 1 READ(LUN,FORM) (VAR(I,J),I=1,XCELLS)
2	-XY	DO 2 J=1,YCELLS 2 READ(LUN,FORM) (VAR(I,J),I=XCELLS,1,-1)
3	X-Y	DO 3 J=YCELLS,1,-1 3 READ(LUN,FORM) (VAR(I,J),I=1,XCELLS)
4	-X-Y	DO 4 J=YCELLS,1,-1 4 READ(LUN,FORM) (VAR(I,J),I=XCELLS,1,-1)
5	YX	DO 5 I=1,XCELLS 5 READ(LUN,FORM) (VAR(I,J),J=1,YCELLS)
6	-YX	DO 6 I=1,XCELLS 6 READ(LUN,FORM) (VAR(I,J),J=YCELLS,1,-1)
7	Y-X	DO 7 I=XCELLS,1,-1 7 READ(LUN,FORM) (VAR(I,J),J=1,YCELLS)
8	-Y-X	DO 8 I=XCELLS,1,-1 8 READ(LUN,FORM) (VAR(I,J),J=YCELLS,1,-1)

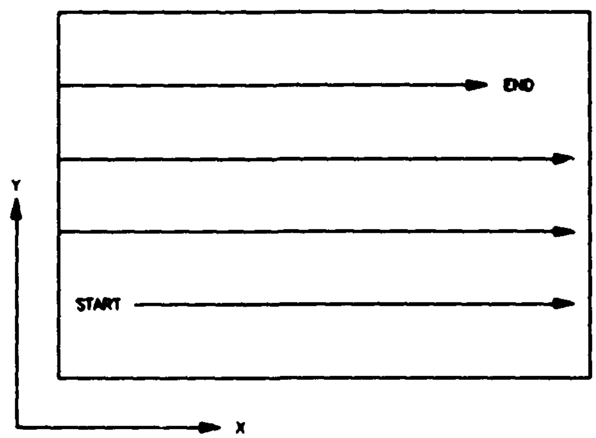


Figure 3-16. Input sequence - option 1

43. The maximum water depth is specified with variable DLIMIT, and any array values deeper than DL^TMIT are set to DLIMIT (in BUNITS). Grid-wide adjustments to land elevations contained in the topography/bathymetry array

can be made with variable LDATUM. The value assigned to this variable is added to all land cells in the grid. Positive LDATUM values will increase land elevations, whereas negative values will decrease elevations. Similarly, grid-wide adjustments to water depths can be made with variable WDATUM. The value assigned to this variable is added to all water cells. Since these cells have negative values, positive WDATUM values produce shallower basins.

44. Changes to the topography/bathymetry array can also be made to individual cells, or a group of cells with record CHNGBATH. This record allows the user to quickly change values assigned to the bathymetry array without editing the array itself. It should be noted that values of variable BATH on the CHNGBATH record are assumed to have units consistent with those selected for bathymetry/topography (i.e., variable BUNITS on record BATHSPEC). Variables X1INDX and X2INDX on the CHNGBATH record specify the minimum and maximum cell numbers in the x-direction, respectively, where the bathymetry/topography value will change. Similarly, variables Y1INDX and Y2INDX on the CHNGBATH record specify the minimum and maximum cell numbers in the y-direction, respectively, where the bathymetry/topography value will change.

Wind-Field Specification

45. Hurricanes can have a constant or variable translational direction. The constant translation option is normally selected for computing the Standard Project Hurricane wind fields. The variable translation option is provided to allow the user to replicate, or hindcast, wind fields produced by historical hurricane events. One WINDSPEC record and one SPHSPEC record is required for either option. In addition, constant translation storms require one TABSPH record, and variable translation storms require, at a minimum, two TABSPH records. Time(s) specified on the TABSPH record(s) are referenced to the start of the simulation, which is 0.0 hr 0.0 min unless the hotstart option is chosen with the STARTUP record (WIFM applications only).

Constant translational hurricane

46. A constant translation storm is specified with the WNTRVL variable set to CONSTANT on the WINDSPEC record. WTYPE must be set to SPH. The units of wind input values (WUNITS) and the atmospheric pressure input values (PUNITS) are also specified on the WINDSPEC record. The wind field can be gradually applied from quiescent conditions to a given (or interpolated) value

by applying a spline fit over a time period specified with variable WFETHR on record WINDSPEC. The constant translational hurricane option requires the forward speed (VTRANS), track angle (HTRACK), atmospheric pressure at the periphery of the storm (PRFPRS), and the effective radius parameter (RMAXE) to be specified on the SPHSPEC record. Track angles are measured using the standard meteorological convention: an angle of zero degrees defines a hurricane traveling from north to south, and that angle increases in the clockwise direction. For example, a hurricane traveling from east to west has a track angle of 90.0 deg. Track angles should not be adjusted to correspond to the computational grid's axes. Models SPH and WIFM perform this task internally. The effective radius parameter is a form factor that adjusts the radial wind distribution for historical events. The effective radius is equal to the radius to maximum winds for the SPH storm.

47. The TABSPH record is used to specify the SPH parameters at a given instant in time (SPHOUR,SPHMIN) where SPHOUR is in hours and SPHMIN is in minutes. The TABSPH record contains the central pressure index (CPI), radius to maximum winds (RMAX), maximum wind speed (MAXWND), angle to maximum winds (AZMUTH) measured clockwise from the forward velocity vector to the maximum wind velocity vector, and wind inflow angle (NGRESS) at a specified time. The landfall point, specified by variables SPHLAT and SPHLNG on record TABSPH, is a reference point that the eye of the hurricane will pass through. Coupled with the track angle, these parameters define the path of the hurricane. The landfall point is normally assigned a latitude and longitude within the study area. However, models SPH and WIFM permit landfall points that are outside the grid limits. This feature is generally used when applying the model to a historical storm event and will be discussed in the next section.

48. The time at which the hurricane reaches the landfall point (relative to the simulation start time) is specified by variables SPHOUR and SPHMIN in record TABSPH. It is more convenient to specify the landfall point and corresponding simulation time rather than specifying the starting location of the hurricane. Models SPH and WIFM compute the starting location internally.

49. As previously noted, variable DELT is the time-step for saving wind-field data for use by a hydrodynamic model and has no effect on the SPH simulation other than setting the other time variables. The times at which wind fields are actually computed are controlled by variable SPHDLT on record SPHSPEC. Usually, wind fields are not computed at each time-step (i.e.,

SPHDLT is larger than DELT). However, models SPH and WIFM have the capability of linearly interpolating wind-field velocities and atmospheric pressures at time-steps when wind-field calculations are not made. The time interval, or frequency at which wind fields are interpolated, is controlled by variable WINTRP in record WINDSPEC. A value of 15.0 min for variable SPHDLT and a 5.0-min value for variable WINTRP are usually sufficient to accurately predict hurricane wind fields for slow-moving storms. However, fast-moving storms require lower values to accurately represent the wind fields.

50. The three time variables (DELT, SPHDLT, and WINTRP) are related in the following way: values for variables SPHDLT and WINTRP must be integer multiples of the time-step (variable DELT on record TIMESPEC) for the computation/interpolation scheme to work properly. For example, given a time-step, DELT, of 1.0 min, SPHDLT equal to 4.0 min, and WINTRP equal to 2.0 min, wind-field calculations will occur at simulation times of 0.0, 4.0, 8.0 min, etc. Wind velocities and atmospheric pressures will be interpolated at simulation times 2.0, 6.0, 10.0 min, etc. (Wind fields are not updated at simulation times 1.0, 3.0, 5.0 min, etc.) If values of 30.0 and 31.0 min are specified for the time-step and variable WINTRP, respectively, wind fields will be interpolated at 930.0-min intervals, the first number divisible by both 30 and 31.

Variable translational hurricane

51. A variable translation storm is specified with WNTRVL set to VARIABLE on the WINDSPEC record. All other variables on the WINDSPEC record are the same as described for a constant translation storm. A variable translation storm requires only the effective radius parameter (RMAXE) and the atmospheric pressure at the storm's periphery (PRFPRS) to be specified on the SPHSPEC record.

52. The first TABSPH record for the variable translation option must specify the wind-field parameters at the start of the simulation. Furthermore, the last TABSPH record must specify the hurricane parameters no earlier than the end of the simulation. For example, if the end of the simulation is at time 12.0 hr 0.0 min, the time specified on the last TABSPH must be greater than or equal to 12.0 hr 0.0 min. It should be noted that for variable translation storms, SPHLAT and SPHLNG specify the latitude and longitude of the storm eye at time SPHOUR,SPHMIN, rather than the landfall point as it was

for a constant translation storm. All other variables on the TABSPH record are the same as described for a constant translation storm.

53. Wind fields are computed only at times specified with the TABSPH records. Models SPH and WIFM do not compute wind fields at intermediate time intervals when the variable translation option is chosen. However, wind fields can be interpolated at intermediate time-steps (WINTRP). The procedure for selecting the wind-field interpolation option was explained in the preceding section.

Output Specification

54. Model SPH provides several options for displaying output, including: numerical gage time-histories at selected grid cells; wind-field vectors at user-specified times during a simulation; and an output listing containing an input data summary and a printout of wind velocity and atmospheric pressure fields. Wind and pressure data files can be used as input to hydrodynamic models as well as wave hindcast models. Data can be displayed in either tabular or graphical form with the post-processing package CMSPOST discussed in Appendix D.

55. The output listing containing a summary of the input data set is generated for every simulation. Error and warning diagnostic messages are also contained in this listing. A sample output listing containing a summary of the input dataset is presented in Figure 3-17.

56. Each record is summarized in tabular form with a heading containing its record identification label followed by a brief description of that record's function. A table is composed of each variable's name, a description of that variable (including its units, when applicable), and an error diagnostic note.

57. Model SPH contains error diagnostic features that inspect an input data set for possible errors. These features include: comparing an inputted value against a range of quantities that are representative for that variable; checking for misspelled character data; and checking for missing data. The error diagnostic note can be assigned three strings, which are "FATAL," for errors where the model cannot execute given the value supplied; "WARN," for data outside the range of values typically selected for that variable; and a null string for instances where an error condition has not been identified.

---- Test No. 1: SPH Storm ----

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*				

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		*	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	26		*	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	24	
DX	SPATIAL STEPSIZE IN X DIRECTION	38216.30		*	DY	SPATIAL STEPSIZE IN Y DIRECTION	38216.30	
GLATT	LATITUDE OF GRID ORIGIN (DEGREES)	28.48		*	GLONG	LONGITUDE OF GRID ORIGIN (DEGREES)	-92.10	
GALIGN	GRID ROTATION FOR EAST (DEGREES)	340.00		*				

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	900.0		*	TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	MINUTES	
TPROV	TIME AT START OF MODEL SIMULATION	0.0		*	TMAX	TOTAL TIME OF SIMULATION	3600.0	
DTGAGS	TIME INTERVAL TO SAVE GAGE DATA	15.00		*	DTHOTS	TIME INTERVAL TO SAVE HOTSTARTS	3600.00	

***** HYDROGRAPH AND VELOCITY MEASUREMENTS: 3 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	5	17		UAVGVAVG		SUBMERGED PIPE LOCATION
2	10	17		UAVGVAVG		DUMP SITE LOCATION
3	15	17		UAVGVAVG		MARSH ISLAND LOCATION

***** TIMES FOR SNAPSHOTS OF DATA SAVED (MINUTES):

600.000 1200.000 2400.000 3600.000

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER	*	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	*	TIMES TO PRINT (MINUTES): START AT	END AT	INTERVAL	NOTES:	*	VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1	*	X= 1	X= 26	Y= 1	Y= 24		*	0.0	3600.0	1.0		*	WP	

***** WINDSPEC CARD: SPECIFICATION OF THE WIND FIELD -

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:

Figure 3-17. Sample output listing

Although this model contains error diagnostic capabilities, the user should thoroughly inspect the input data summary to ensure that the data are correct.

58. Field arrays (e.g., bathymetry, atmospheric pressure, and wind velocity) are printed along with the input data summary by including one or more PRWINDOW records. The user can control printing of field arrays through the course of a simulation by specifying the starting (WPRSTR) and ending (WPREND) times, together with the time interval (WPRINT), at which the data will be printed. Furthermore, the user can specify printing of subgrid regions, as opposed to the entire grid if they so choose. This is done by specifying the x- and y-boundaries of the subgrid region with variables WXCEL1, WXCEL2, WYCEL1, and WYCEL2.

59. Gage time-histories of wind velocity and atmospheric pressures are saved with record RECGAGE. One RECGAGE record is required for each desired output location where both the wind velocity and the atmospheric pressure are to be saved. A maximum of 120 gages, each containing up to 1,000 points, can be processed. All gage time-histories are stored in one file and are processed by programs HYDADD, HYDLST, and HYDPLT in package CMSPOST.

60. Variables GXPOS and GYPOS on record RECGAGE define the grid location where wind velocity and atmospheric pressures are saved. The time interval at which these data are stored is controlled by variable DTGAGS on record TIMESPEC. Variable GTYPE on record RECGAGE is only applicable to averaging water velocities generated by model WIFM and does not affect output from model SPH.

61. Record RECSNAPS allows the user to store wind velocity and atmospheric pressure data for generating vector plots. The stored data can also be used as input to other models. Data can be saved at regular time intervals (SNPTYP = INTERVAL), at specific times during a simulation (SNPTYP = TIMES), or both; however, all time indices <u>must</u> be integer multiples of the time-step, DELT. More than one RECSNAPS record can be used, and up to 100 snapshots can be saved in a file. These data can be processed with programs SNAPCON, SNAPLST, and SNAPVEC, which reside in package CMSPOST.

PART V: DEFINITION OF INPUT DATA FORMAT

62. The input data set format was designed to resemble the format required by the series of models released by the US Army Engineer Hydrologic Engineering Center. It is the intent that this structure, being familiar to Corps personnel, will reduce the time needed to learn this system. The general format of the input data set records, where a record refers to one line of data, is presented below:

a. Each record is divided into 10 fields containing 8 columns each.

b. Field 1, columns 1 through 8, contains a mnemonic identification label that describes the purpose or function of each record.

c. Fields 2 through 10 contain data that may be real, integer, or character in type. Integers must be right justified. Real numbers must also be right-justified if the decimal point is omitted. Character data do not need to be right- or left-justified.

d. Array data, such as depths, are read with DO or Implied DO loops. No label is required for each record containing array data. However, a general specification record such as BATHSPEC, which defines bathymetric attributes, must precede that array.

63. Spelling of record identification labels and alphanumeric variables is important. Misspelled entries will result in either recognized error conditions that force the model to abort execution or bypassing of desired user-defined operations, such as saving time-history data.

64. Certain records and variables have been assigned default values in the model for minimizing input data and computer resources. Thus, not all input data records will be needed for each application, and only those records pertinent to the simulation or required by the model should be included. Default values are representative of those chosen in previous studies performed by CERC. Although these quantities may not be applicable to all studies, they can serve as a guide when selecting replacement values.

65. Default values are processed when the record field corresponding to that variable is blank. Hence, the user must be careful when leaving fields blank in a record; blank fields will not necessarily result in a variable being assigned a value of zero. These variables and their respective default values are noted in Appendix 3-A. The following discussion pertains to the general format of the input records given in Appendix 3-A.

66. Each record is presented in a standardized tabular format and has as its heading the mnemonic identification label or name with a brief description of its function. Following its name, the record has an abbreviated note documenting whether it is required for a simulation. These abbreviations have the following definitions:

(Req) Record or variable is required for each simulation.

(Opt) Record or variable is optional. Omitting this item results in either the default value being used or the defined operation not being performed.

(C-opt) Record or variable is required if related or parent options have been selected.

For example, record TIMESPEC, presented in Appendix 3-A, contains the note (Req), meaning that this record must reside in the input data set for each simulation. Record CHNGBATH contains the note (Opt) meaning this record is optional and is used only when changes to the bathymetric data are desired. Record XSTRETCH contains the note (C-opt), meaning this record is required only if a stretched Cartesian grid has been specified on the GRIDSPEC record.

67. Input variables, presented in column 2 of each table, are referenced to their respective record fields shown in column 1. Generally, data for each variable occupy a single 8-column data field. However, variables assigned titling or formatting information can occupy several fields.

68. Variable attributes are presented in columns 3 through 6 of each table. Valid data types are listed in column 3, and can be real, integer, or alphanumeric. Abbreviations presented in this column are described below:

Char*16 Alphanumeric character string containing up to 16 characters

Char*8 Alphanumeric character string containing up to 8 characters

Integer Integer data

Real Real (floating point) data

69. Column 4 of each table defines whether the respective variable must be assigned a value. Abbreviations listed in this column have identical meanings as those for the records. Default values are listed in column 5. A blank entry in this column denotes that the respective variable is not assigned a default value.

70. Column 6 of each table lists the variables' permitted data type or all valid character strings. Variables having integer or real data types are specified with the following notation:

A	Alphanumeric values
+R	Positive real values
R	Positive, zero, or negative real values
+I	Positive integer values
I	Positive, zero, or negative integer values

71. Variable definitions are listed in column 7 of each table. Variables whose quantities are unit-dependent contain a reference to that variable designating its system of units. For example, variable TMAX is assigned a value having units defined by variable TUNITS. Variables defining input data units, and on which record they reside, are presented below.

Variable	Record	Definition
BUNITS	BATHSPEC	bathymetry/topography data
GUNITS	GRIDSPEC	numerical grid data
PUNITS	WINDSPEC	atmospheric pressure data
SUNITS	GENSPECS	model computations and output
TUNITS	TIMESPEC	time-dependent variables
WUNITS	WINDSPEC	wind velocity data

PART VI: TEST PROBLEMS

72. This section contains two test problems that demonstrate model capabilities and serve as a guide in developing an input data set. The first problem is an example of an SPH simulation, and the second is a hindcast simulation of Hurricane Danny, which struck the Louisiana coast in August 1985. Each example is applied to the same study site (Figure 3-18) and uses the same computational grid (Figure 3-19). Two simplifications were made while constructing this grid so that the model's capabilities could be clearly presented. These simplifications are (a) limiting the grid's reach in the seaward direction and (b) minimizing the number of cells covering the study area. How these factors affect a study are explained later in this section.

73. The grid extends in the longshore direction from Upper Mud Lake to East Cote Blanche, Louisiana. The grid's northern boundary was chosen so that Grand Lake and Vermilion Bay are included in the model, and the southern boundary extends to a water depth of approximately 22 fathoms.

74. The grid's origin was arbitrarily chosen at its southwest corner. (Any of the four corners can be chosen as the origin.) Thus, the x-axis corresponds with the longshore axis, and the y-axis extends in the landward direction. Total grid lengths in the x- and y-directions are 163.4 and 150.9 n. m., respectively.

75. The grid is aligned at an angle of 340.0 deg, measured counter-clockwise from east to the x-axis. At this angle, the x-axis roughly parallels the shoreline, providing a smooth representation of the land-water interface. Alignments that produce jagged, "saw-tooth" shorelines should be avoided because surface friction effects would not be properly imposed on the wind field.

76. For storm surge analyses performed with a hydrodynamic model, the grid should extend to the seaward edge of the continental shelf. To simulate the combined effects of tide and pressure anomaly, the hydrodynamic model adds the two components at the outer seaward boundary. This linear superposition procedure is most valid in deep water since the tidal signal is attenuated, primarily due to bottom friction, in shallow water. Hence, if the grid was constructed for an actual study, it would extend to a water depth of at least 300 ft.

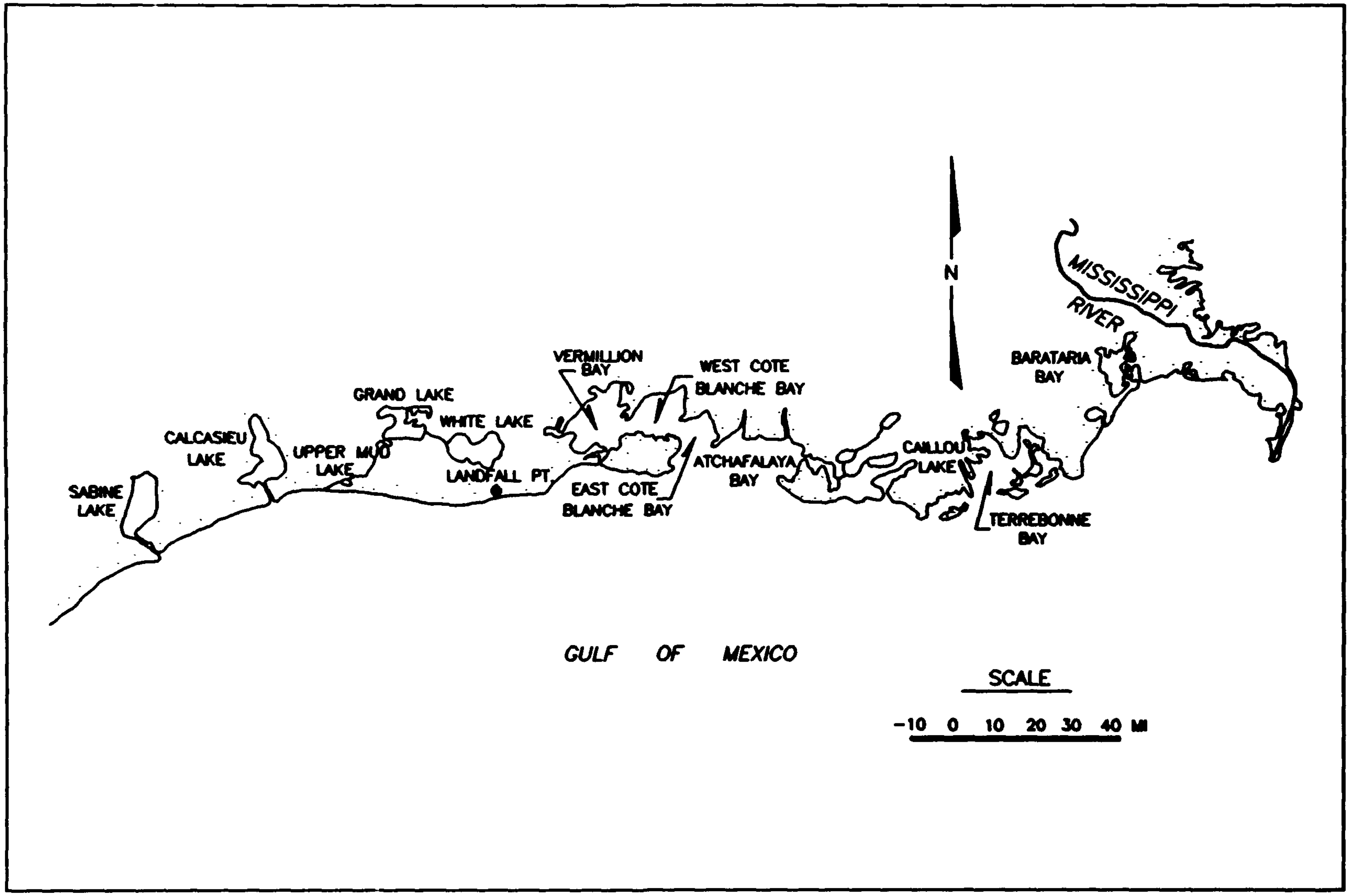


Figure 3-18. SPH study site: Coast of Louisiana

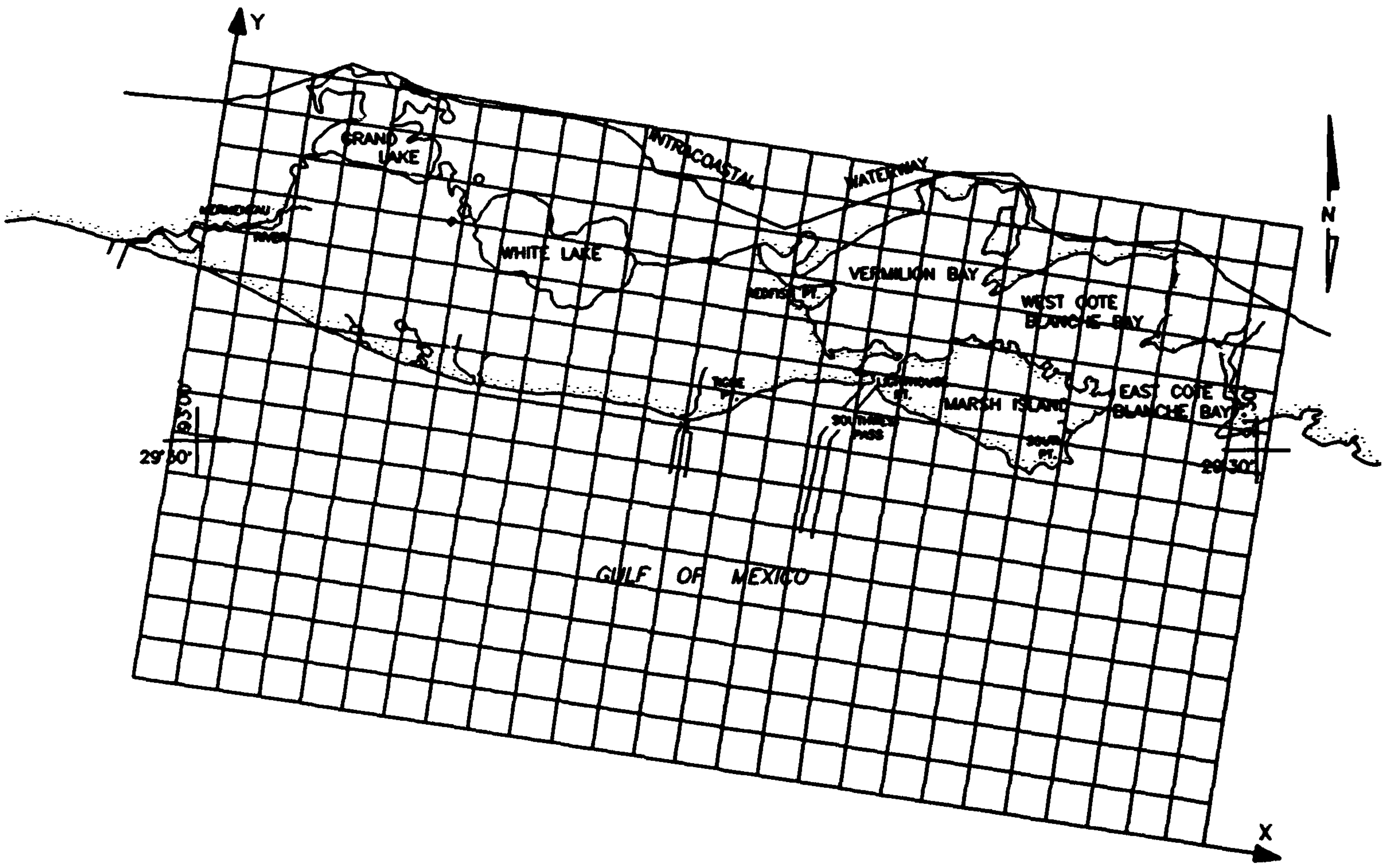


Figure 3-19. Computation grid for model test simulations

77. The grid is composed of 26 cells in the x-direction and 24 cells in the y-direction, with each cell measuring 38,216.3 by 38,216.3 ft. Because of the large cell dimensions, this grid is too coarse for use in a hydrodynamic model. Greater resolution is needed, particularly in the bay areas, to accurately represent the hydraulic features influencing currents and water levels. Typically, a grid used in a hydrodynamic model would have cell widths of 100 to 500 ft in channel and inlet areas, and cell widths of approximately 10,000 ft along the outer seaward boundary. Additional guidance in generating grids is contained in Appendix A.

Test Problem 1

78. This problem illustrates the simulation of an SPH storm whose landfall point is latitude 29.6 deg N and longitude 92.7 deg W. From Figure 3-6, this location is at milepost 450 n. m. The SPH parameters for this location are:

a. Peripheral pressure is equal to 29.77 in. Hg.

b. Central pressure is equal to 27.37 in. Hg (Figure 3-7).

c. Forward speed is equal to 25.0 knots (Figure 3-8).

d. Radius to maximum winds is equal to 20.0 n. m. (Figure 3-9).

e. Inflow angle is equal to 7.5 deg (Figure 3-10).

f. Track angle, for category B (Table 3-1), is equal to 140.0 deg (Figure 3-11).

g. Air density coefficient, K, is equal to 67 (Figure 3-12).

h. Maximum rotational wind speed is equal to 101.20 knots (Equation 3-20).

79. Figures for the parameter's forward speed, radius to maximum winds, and track direction contain a range of suitable values. Choosing the maximum value for each particular parameter does not guarantee that the predicted wind fields will generate the maximum storm surge level. Several parameter combinations must be tested when performing a storm surge analysis to ensure that the maximum storm surge level has been obtained.

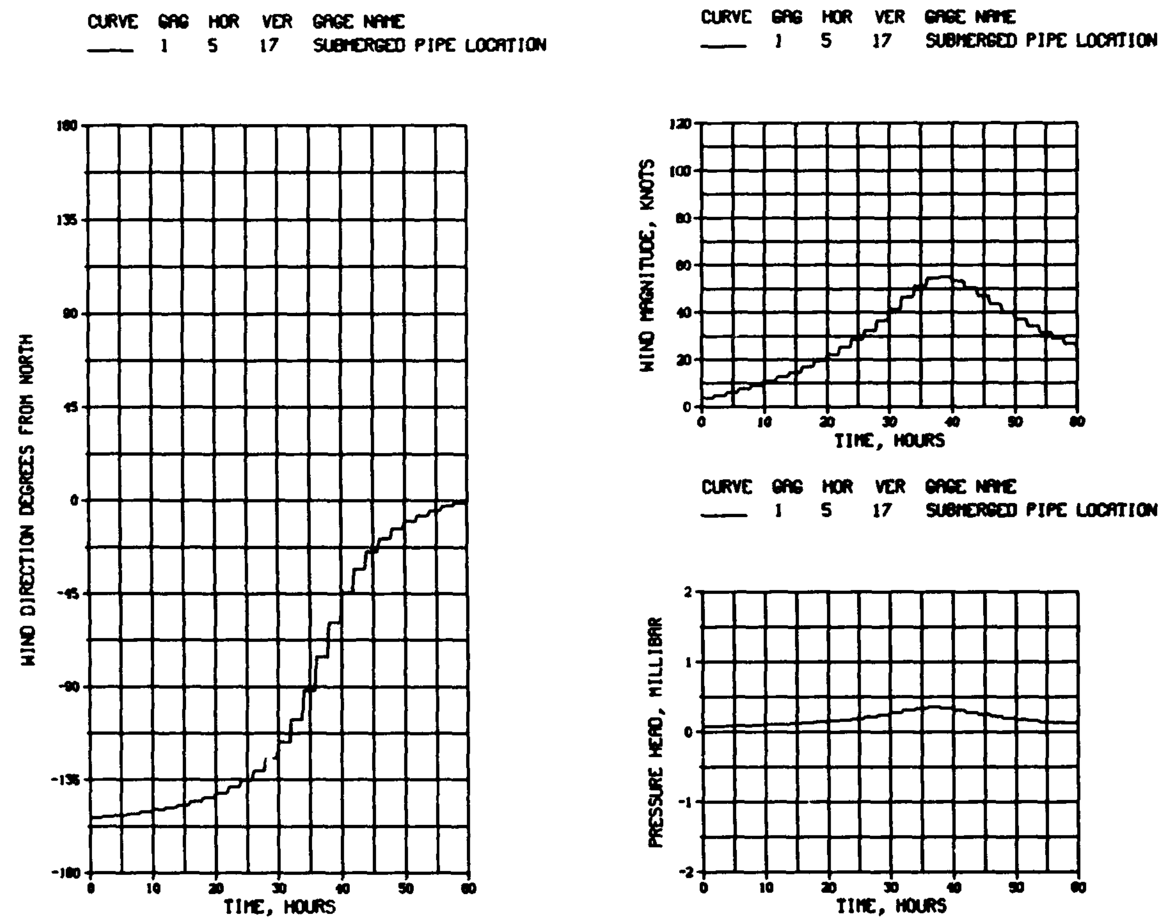
80. This test problem's input data set is presented in Table 3-5. Three time-series graphs, showing wind magnitude and direction, and atmospheric pressure anomalies are presented in Figures 3-20 through 3-22. The

simulation's input data summary is presented in Table 3-6. Vector wind-field graphs are presented in Figures 3-23 through 3-25.

Table 3-5

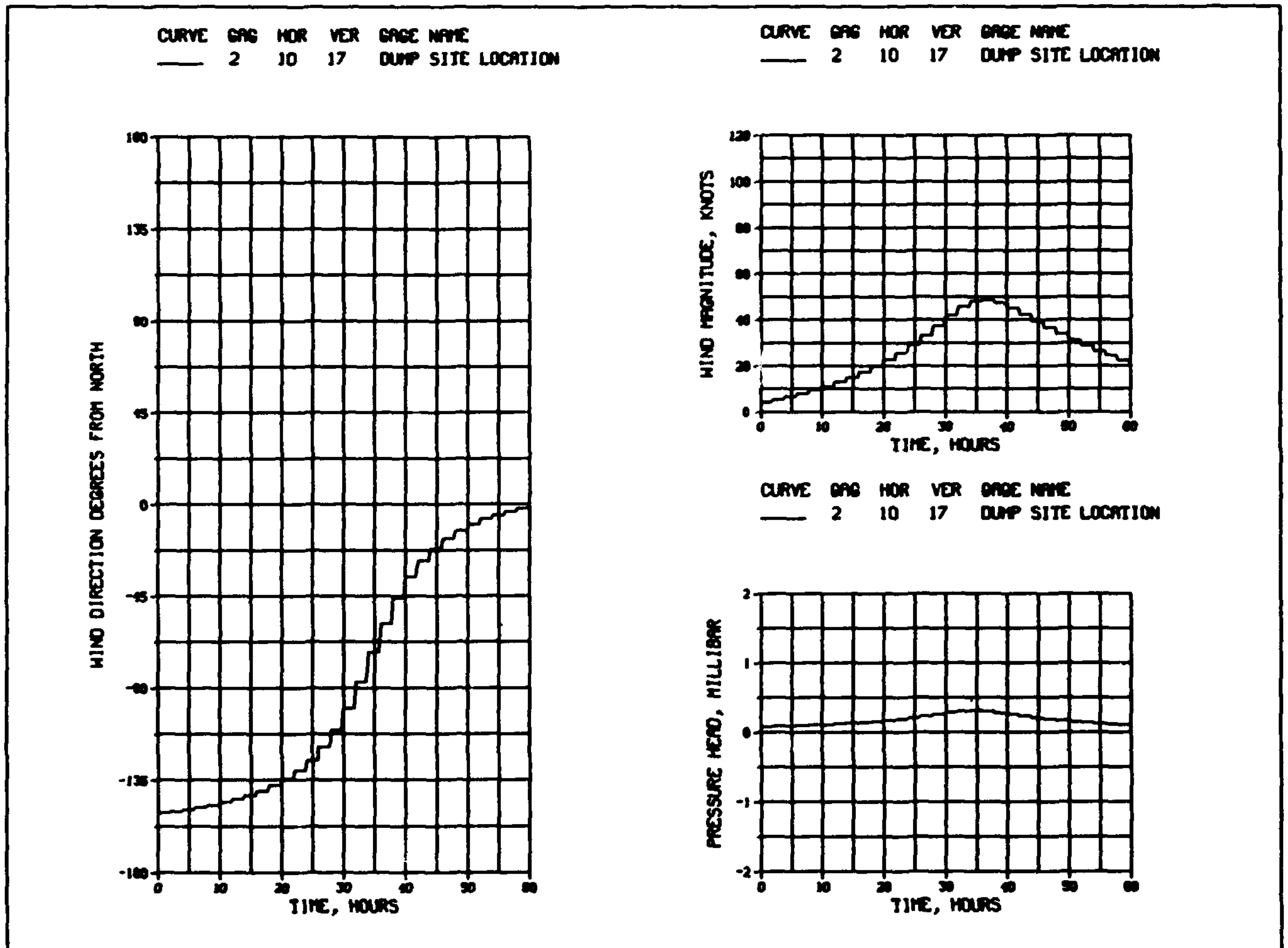
Input Data Set for Test 1

```
GENSPECS       Test No. 1:  SPH Storm
ENGLISH
TIMESPEC   900.0 MINUTES      0.0  3600.0    15.0
GRIDSPEC RECTANG ENGLISH       26       24 38216.3 38216.3   28.48    92.10 340.0
PRWINDOW
RECGAGE        5       17          SUBMERGED PIPE LOCATION
RECGAGE       10       17          DUMP SITE LOCATION
RECGAGE       15       17          MARSH ISLAND LOCATION
RECSNAPS   TIMES    600.    1200    2400    3600
WINDSPEC     SPHCONSTANT   KNOTSMILLIBAR     5.0
SPHSPEC 1014.000    40.0   120.0   135.0    12.0
TABSPH       40.     30.   29.6    92.7    987.00    40.0    80.0 180.0    29.0
BATHSPEC                                     YX      (6X,9F8.1)
   1     -14.0   -14.0   -13.0   -13.0   -13.0   -13.0   -12.0    -9.0   -10.0
          -9.0    -9.0    -7.8    -8.0    -7.5    -7.5    -6.5    -5.8    -4.5
          -2.0     .33    .667     1.0    1.33     1.5
   2     -16.0   -15.0   -14.0   -12.0   -12.0   -13.0   -12.0    -9.0   -10.0
          -9.0    -9.0    -9.0    -8.0    -8.0    -8.0    -6.5    -6.3    -3.5
          -2.0     .33    .667     1.0    1.33     1.5
   3     -17.0   -15.0   -14.0   -12.0   -12.0   -13.0   -13.0   -11.0    -9.0
         -10.0   -10.0    -9.0    -9.0    -8.0    -8.0    -6.5    -6.0    -4.0
           .33    .667     1.0    1.33     1.5   1.667
   4     -18.0   -15.0   -14.0   -13.0   -12.0   -13.0   -13.0   -12.0   -10.0
         -10.0   -10.0    -9.0    -8.0    -8.0    -8.0    -6.5    -5.0    -3.0
           .33    .667     1.0    1.33     1.5   1.667
   5     -17.0   -15.0   -14.0   -13.0   -12.0   -13.0   -13.0   -13.0   -11.0
          -9.0   -10.0    -9.0    -9.0    -8.0    -7.5    -6.5    -5.0    -2.5
           .33    .667     1.0    1.33     1.5   1.667
   6     -17.0   -16.0   -14.0   -14.0   -13.0   -13.0   -13.0   -13.0   -12.0
         -10.0   -10.0    -9.0    -9.0    -9.0    -7.5    -6.8    -5.0     .33
          .667     1.0    1.33     1.5   1.667   1.833
   7     -17.0   -16.0   -16.0   -15.0   -14.0   -13.0   -14.0   -13.0   -12.0
         -11.0   -10.0    -9.0    -9.0    -8.0    -7.5    -6.0    -5.0     .33
          .667     1.0    1.33     1.5   1.667   1.833
   8     -17.0   -17.0   -16.0   -15.0   -14.0   -13.0   -14.0   -13.0   -12.0
         -11.0   -10.0    -9.0    -9.0    -8.0    -7.0    -6.0    -3.0     .33
          .667     1.0    1.33     1.5   1.667   1.833
```



Test No. 1: SPH Storm

Figure 3-20. Test 1 hydrograph for gage 1



Test No. 1: SPH Storm

Figure 3-21. Test 1 hydrograph for gage 2

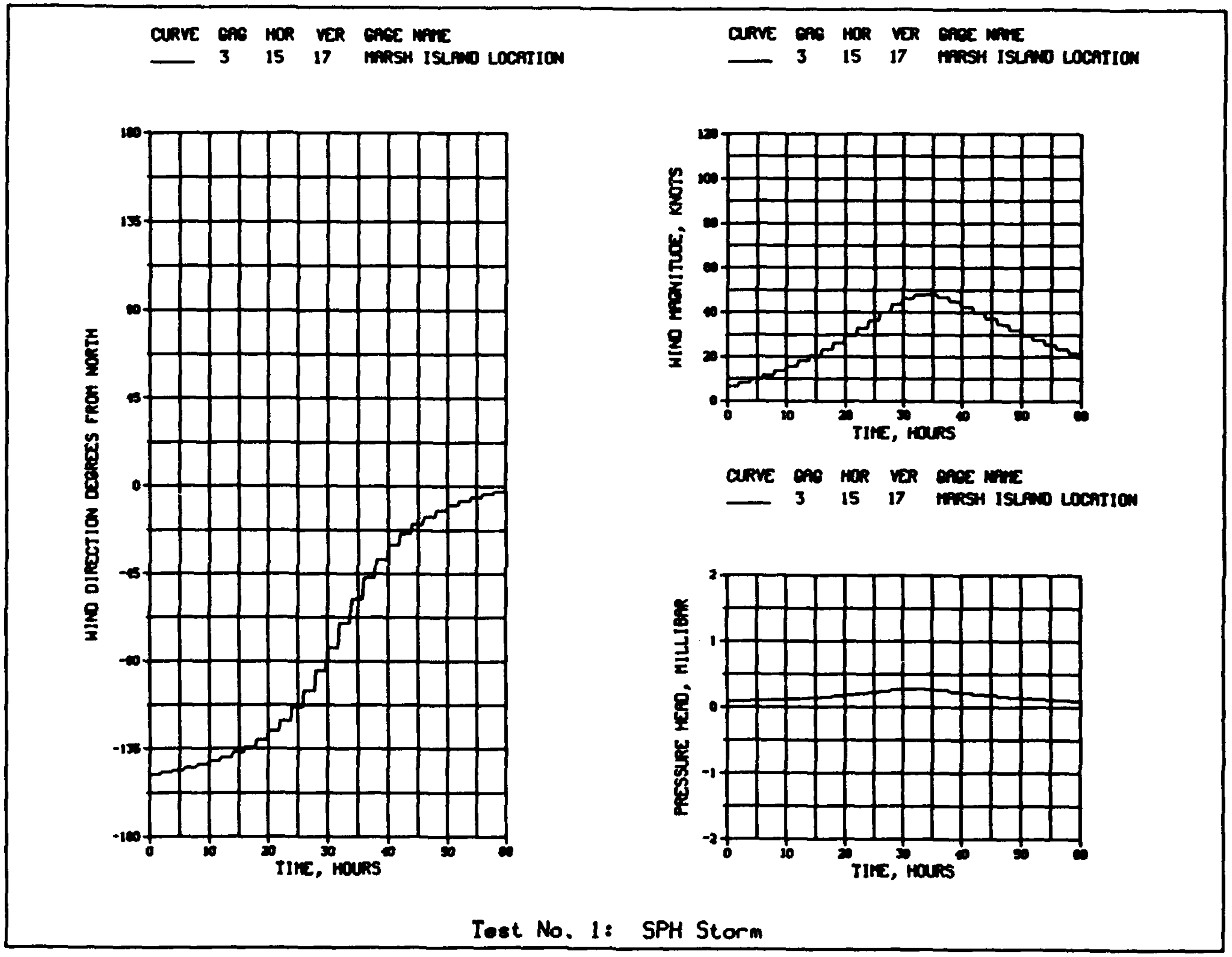


Figure 3-22. Test 1 hydrograph for gage 3

Table 3-6

Input Data Summary for Test 1

---- Test No. 1: SPH Storm ----

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*				

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		*	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	26		*	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	24	
DX	SPATIAL STEPSIZE IN X DIRECTION	38216.30		*	DY	SPATIAL STEPSIZE IN Y DIRECTION	38216.30	
GLATT	LATITUDE OF GRID ORIGIN (DEGREES)	28.48		*	GLONG	LONGITUDE OF GRID ORIGIN (DEGREES)	-92.10	
GALIGN	GRID ROTATION FOR EAST (DEGREES)	340.00		*				

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	900.0		*	TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	MINUTES	
TPROV	TIME AT START OF MODEL SIMULATION	0.0		*	TMAX	TOTAL TIME OF SIMULATION	3600.0	
DTGAGS	TIME INTERVAL TO SAVE GAGE DATA	15.00		*	DTHOTS	TIME INTERVAL TO SAVE HOTSTARTS	3600.00	

***** HYDROGRAPH AND VELOCITY MEASUREMENTS: 3 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	5	17		UAVGVAVG		SUBMERGED PIPE LOCATION
2	10	17		UAVGVAVG		DUMP SITE LOCATION
3	15	17		UAVGVAVG		MARSH ISLAND LOCATION

***** TIMES FOR SNAPSHOTS OF DATA SAVED (MINUTES):

600.000 1200.000 2400.000 3600.000

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER	*	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	*	TIMES TO PRINT (MINUTES): START AT	END AT	INTERVAL	NOTES:	*	VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1	*	X= 1	X= 26	Y= 1	Y= 24		*	0.0	3600.0	1.0		*	WP	

***** WINDSPEC CARD: SPECIFICATION OF THE WIND FIELD -

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:

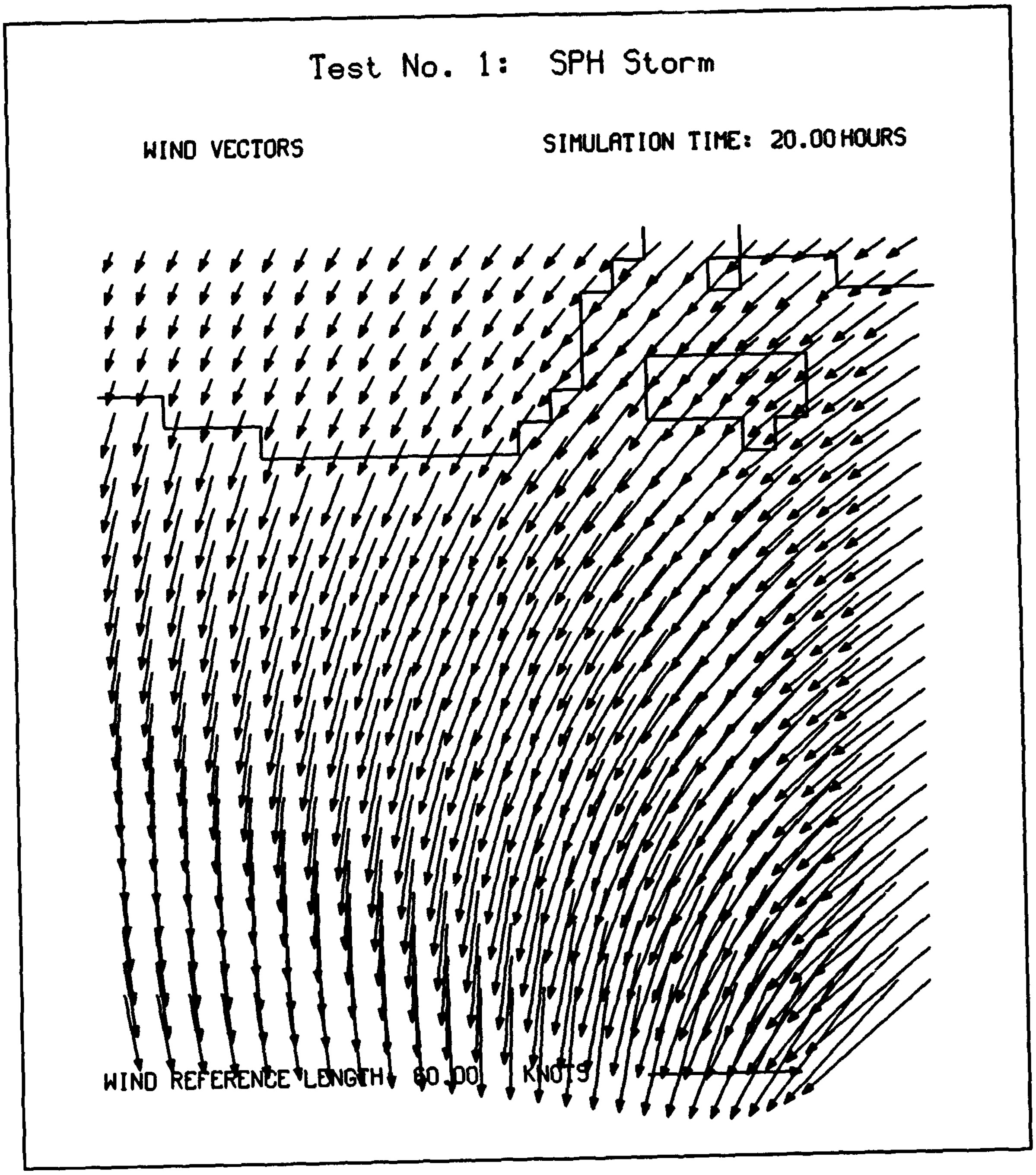


Figure 3-23. Test 1 wind-field snapshot at hour 20

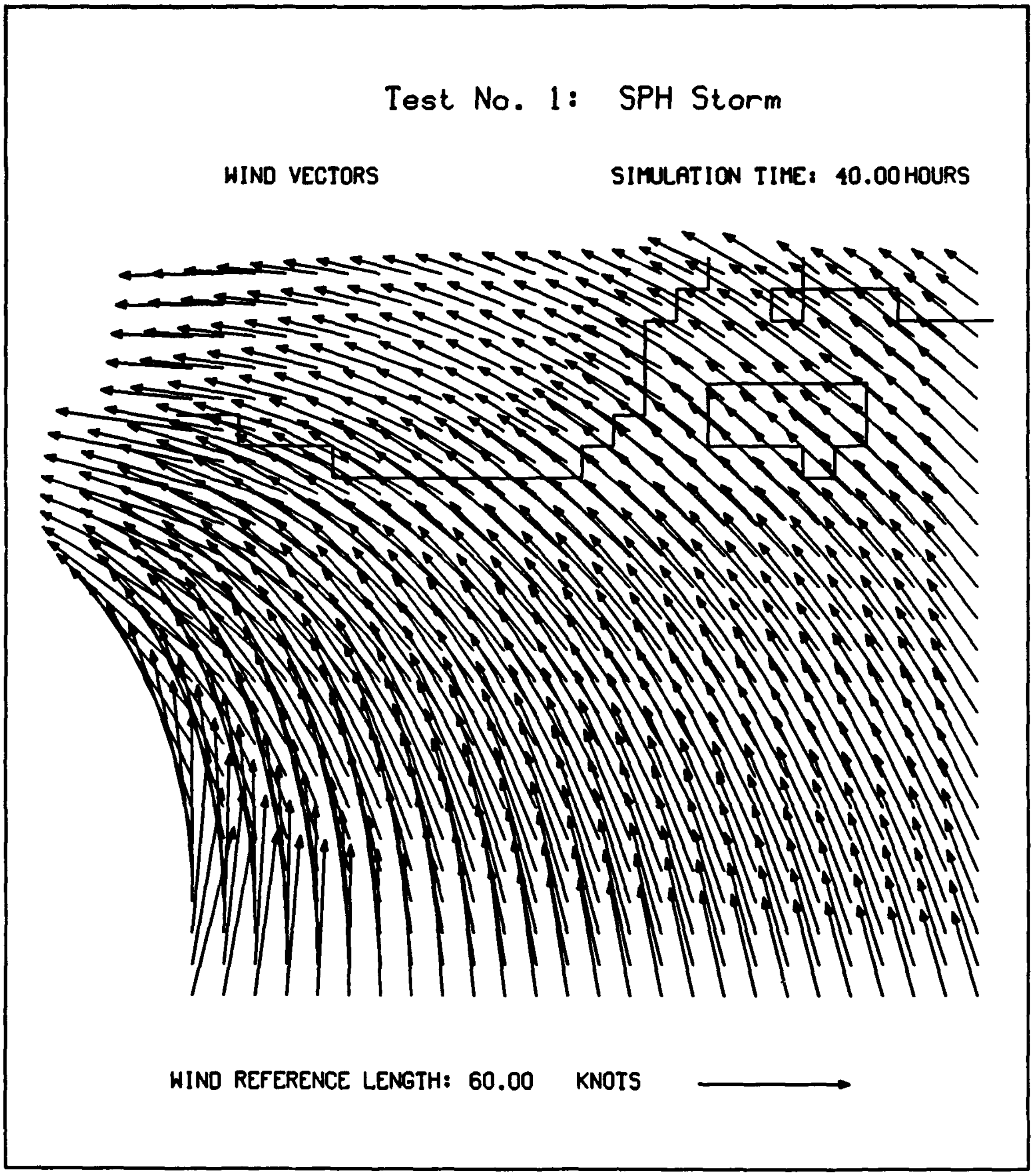


Figure 3-24. Test 1 wind-field snapshot at hour 40

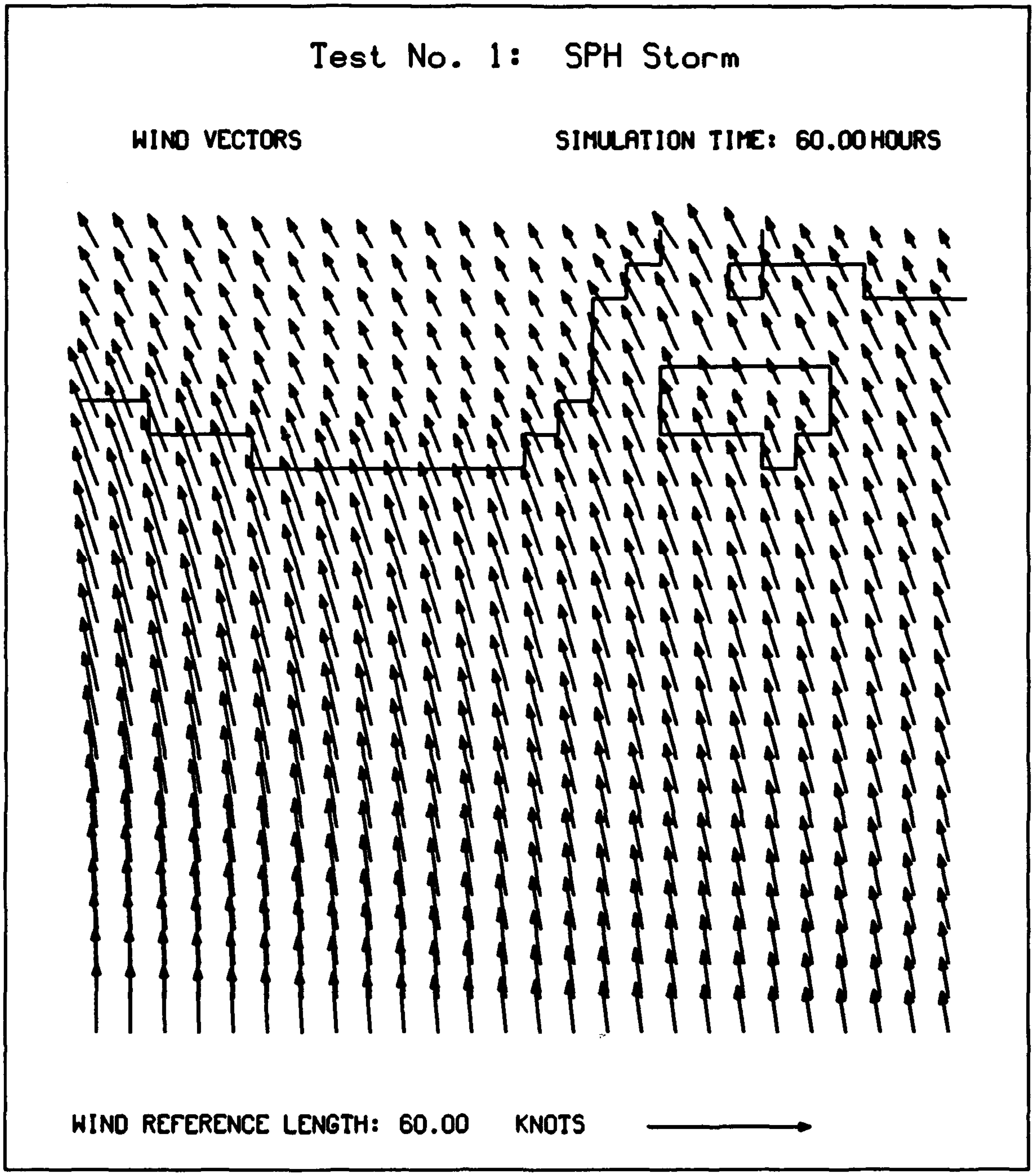


Figure 3-25. Test 1 wind-field snapshot at hour 60

Test Problem 2

81. This problem is a hindcast simulation of Hurricane Danny, which struck the Louisiana coast in August 1985. Figure 3-26 illustrates the approximate track of Danny as it traveled across the Gulf of Mexico and the southern United States. Hurricane data used in this example were obtained from Garcia and Hegge (1987).

82. The simulation began at 0000 Greenwich mean time (GMT) 14 August 1985 and concluded 60 hr later at 1200 16 August 1985. Hurricane Danny reached landfall at approximately 1630 15 August 1985, or at simulation time 40 hr. The simulation was started 40 hr before landfall so that if a hydrodynamic model were used to study the resulting storm surge, the model would have sufficient time in which to develop accurate circulation fields. In addition, starting with low wind velocities would prevent the formation of artificial waves induced by shocking the model with high wind velocities.

83. For the first 18 hr during the simulation, Danny was classified as a tropical storm with wind speeds increasing from 35 knots, at 0000 14 August 1985, to 60 knots at 1800 14 August 1985. During this period, its forward speed remained fairly steady within the range of 11.5 to 12.4 knots, while its central pressure dropped from 1010 to 1001 mb.

84. At 0000 15 August 1985, having wind speeds of 70 knots, Danny was classified as a category 1 hurricane on the Saffir-Simpson scale. Central pressure steadily dropped from 997 to 987 mb at the time of landfall, and wind speeds increased to 80 knots. For the next 20 hr, the hurricane steadily lost intensity as it moved inland, with maximum wind speeds diminishing to 30 knots, and the central pressure increased to 1,000 mb. A summary of hurricane parameters is presented in Table 3-7.

85. This test problem's input data set is presented in Table 3-8. Three time-series graphs, showing wind magnitude and direction, and atmospheric pressure deficits are presented in Figures 3-27 through 3-29. Vector wind-field graphs are presented in Figures 3-30 through 3-32. The simulation's input data summary is presented in Table 3-9.

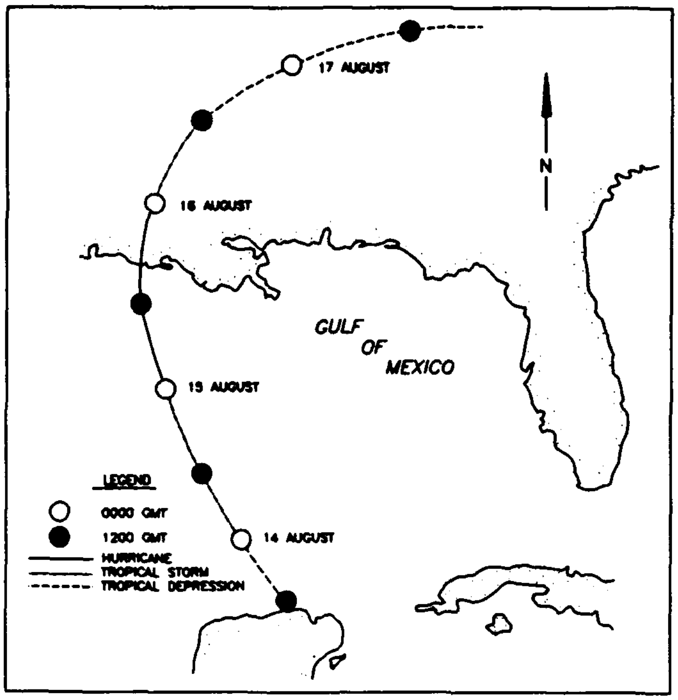


Figure 3-26. Approximate path of Hurricane Danny, August 1985

Table 3-7

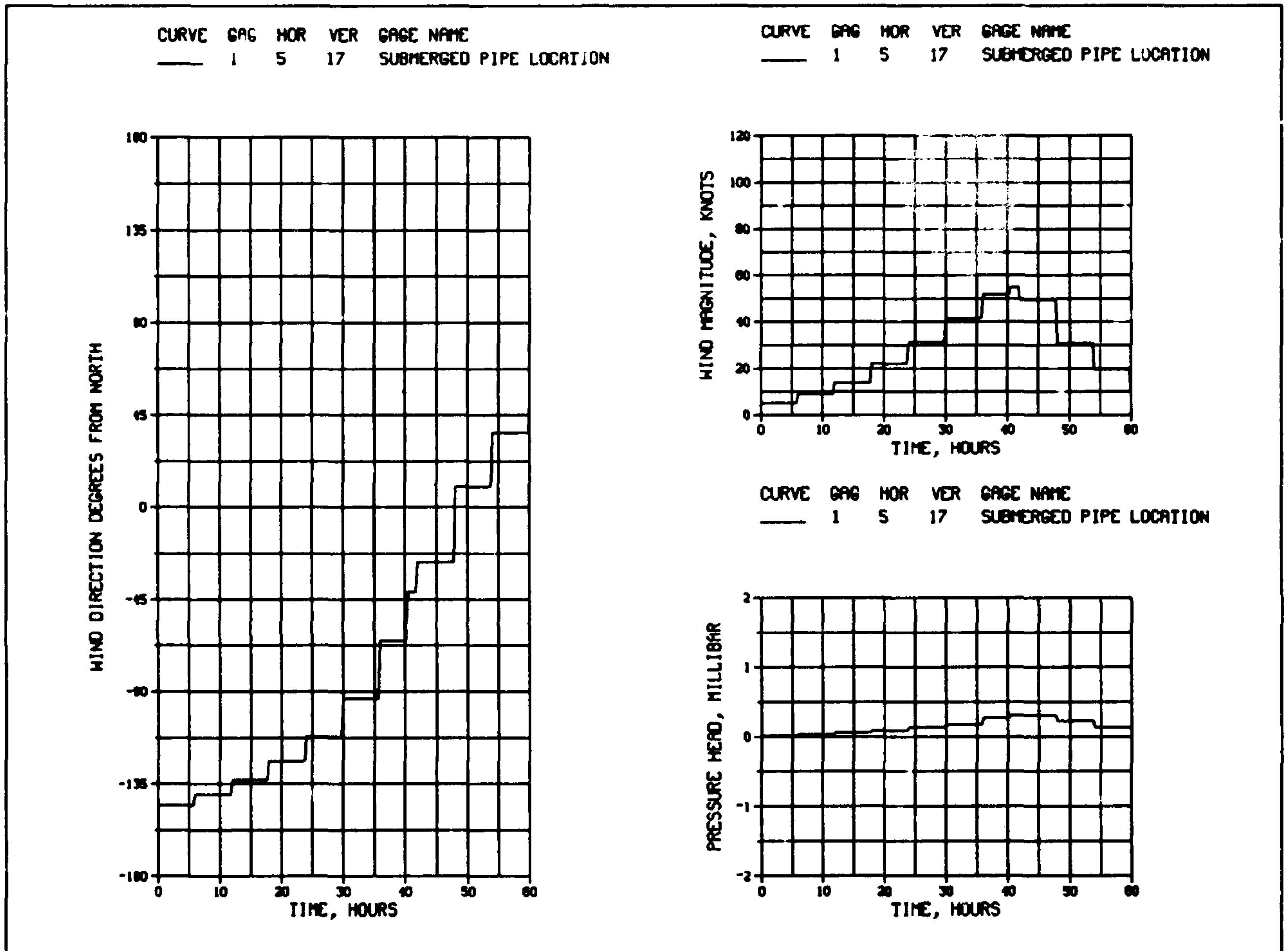
Preliminary Best Track Data for Hurricane Danny

Date	Time GMT	Position Lat	Position Long	CPI mb	Wind knots
8/14	0000	23.7	87.8	1010	35
8/14	0600	24.4	88.8	1007	45
8/14	1200	25.1	89.8	1004	50
8/14	1800	25.9	90.7	1001	60
8/15	0000	26.8	91.5	997	70
8/15	0600	27.8	92.2	995	75
8/15	1200	28.9	92.6	988	80
8/15	1630	29.6	92.7	987	80
8/15	1800	30.0	92.7	988	70
8/16	0000	31.0	92.4	992	50
8/16	0600	32.0	92.0	997	40
8/16	1200	32.9	91.4	1000	30
8/16	1800	33.7	90.4	1002	30

Table 3-8

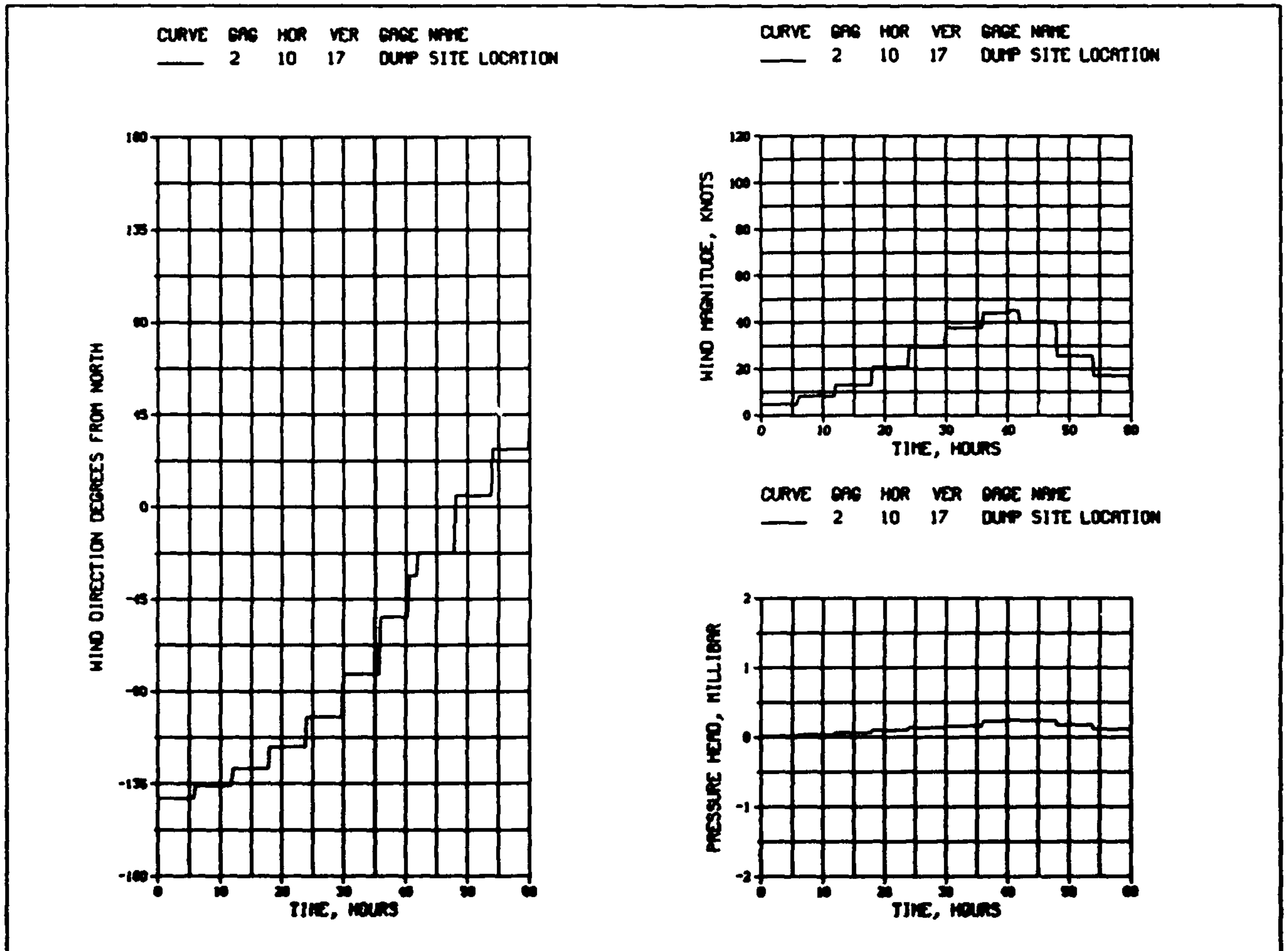
Input Data Set for Test 2

```
GENSPECS       Test No. 2:  Hindcast Storm
ENGLISH
TIMESPEC   900.0 MINUTES     0.0  3600.0    15.0
GRIDSPEC RECTANG ENGLISH      26       24 38216.3 38216.3    28.48    92.10
340.0
PRWINDOW
RECGAGE        5       17        SUBMERGED PIPE LOCATION
RECGAGE       10       17        DUMP SITE LOCATION
RECGAGE       15       17        MARSH ISLAND LOCATION
RECSNAPS   TIMES     600.    1200    2400     3600
WINDSPEC     SPHVARIABLE   KNOTSMILLIBAR      5.0
SPHSPEC 1014.000     40.0    60.0   168.0    11.7
TABSPH     00.      00.  23.700  87.800 1010.00     60.0     35.0 127.32      31.0
TABSPH     06.      00.  24.400  88.800 1007.00     60.0     45.0 127.47      31.0
TABSPH     12.      00.  25.100  89.800 1004.00     60.0     50.0 134.4       31.0
TABSPH     18.      00.  25.900  90.700 1001.00     60.0     60.0 141.31      31.0
TABSPH     24.      00.  26.800  91.500  997.00     50.0     70.0 147.98      31.0
TABSPH     30.      00.  27.8    92.2    995.00     45.0     75.0 162.17      31.0
TABSPH     36.      00.  28.9    92.6    988.00     40.0     80.0 172.86      30.0
TABSPH     40.      30.  29.6    92.7    987.00     40.0     80.0 180.0       29.0
TABSPH     42.      00.  30.0    92.7    988.00     40.0     70.0 194.56      29.0
TABSPH     48.      00.  31.000  92.400  992.00     37.0     50.0 198.92      29.0
TABSPH     54.      00.  32.000  92.000  997.00     37.0     40.0 209.48      29.0
TABSPH     60.      00.  32.900  91.400 1000.00     37.0     30.0 209.48      29.0
BATHSPEC                                     YX      (8X,9F8.1)
   1     -14.0   -14.0   -13.0   -13.0   -13.0   -13.0   -12.0    -9.0   -10.0
          -9.0    -9.0    -7.8    -8.0    -7.5    -7.5    -6.5    -5.8    -4.5
          -2.0     .33    .667     1.0    1.33     1.5
   2     -16.0   -15.0   -14.0   -12.0   -12.0   -13.0   -12.0    -9.0   -10.0
          -9.0    -9.0    -9.0    -8.0    -8.0    -8.0    -6.5    -6.3    -3.5
          -2.0     .33    .667     1.0    1.33     1.5
   3     -17.0   -15.0   -14.0   -12.0   -12.0   -13.0   -13.0   -11.0    -9.0
         -10.0   -10.0    -9.0    -9.0    -8.0    -8.0    -6.5    -6.0    -4.0
           .33    .667     1.0    1.33     1.5   1.667
   4     -18.0   -15.0   -14.0   -13.0   -12.0   -13.0   -13.0   -12.0   -10.0
         -10.0   -10.0    -9.0    -8.0    -8.0    -8.0    -6.5    -5.0    -3.0
           .33    .667     1.0    1.33     1.5   1.667
   5     -17.0   -15.0   -14.0   -13.0   -12.0   -13.0   -13.0   -13.0   -11.0
          -9.0   -10.0    -9.0    -9.0    -8.0    -7.5    -6.5    -5.0    -2.5
           .33    .667     1.0    1.33     1.5   1.667
   6     -17.0   -16.0   -14.0   -14.0   -13.0   -13.0   -13.0   -13.0   -12.0
         -10.0   -10.0    -9.0    -9.0    -9.0    -7.5    -6.8    -5.0     .33
          .667     1.0    1.33     1.5   1.667   1.833
```



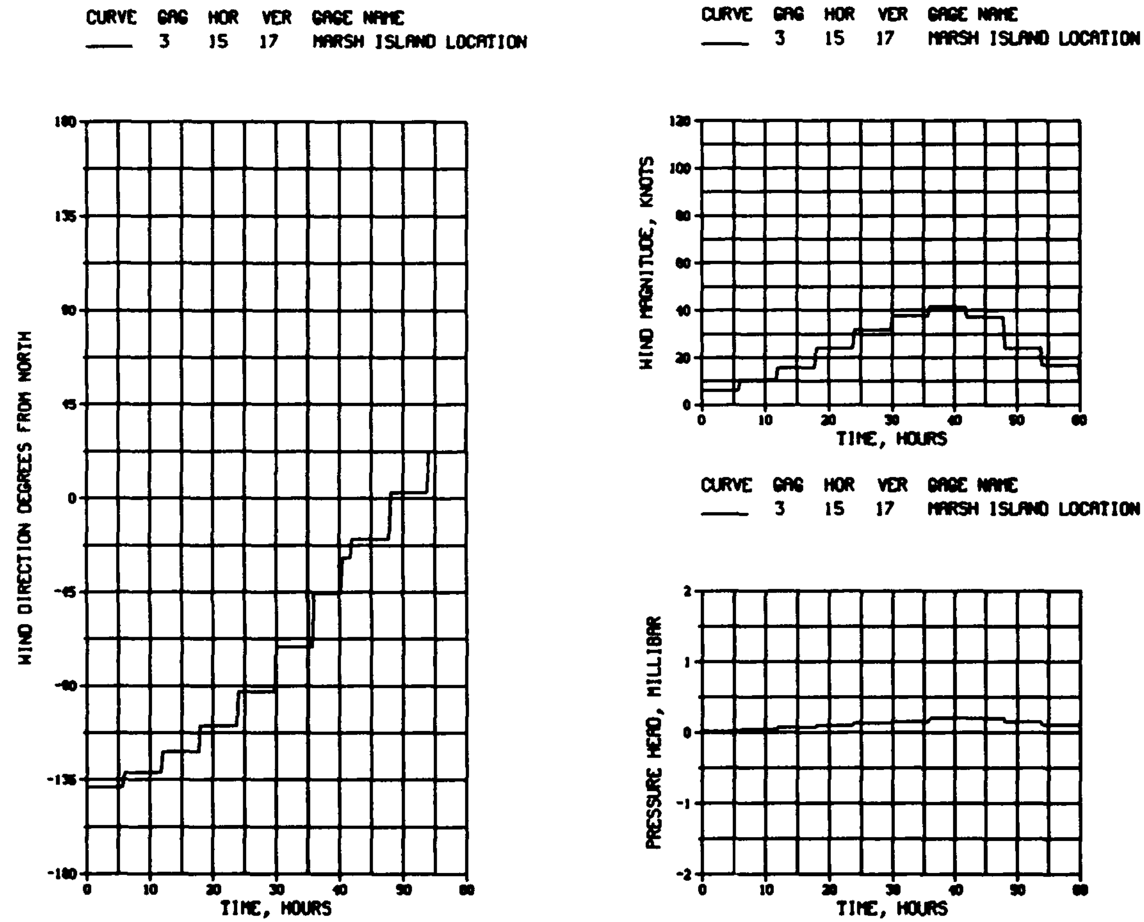
Test No. 2: Hindcast Storm

Figure 3-27. Test 2 hydrograph for gage 1



Test No. 2: Hindcast Storm

Figure 3-28. Test 2 hydrograph for gage 2



Test No. 2: Hindcast Storm

Figure 3-29. Test 2 hydrograph for gage 3

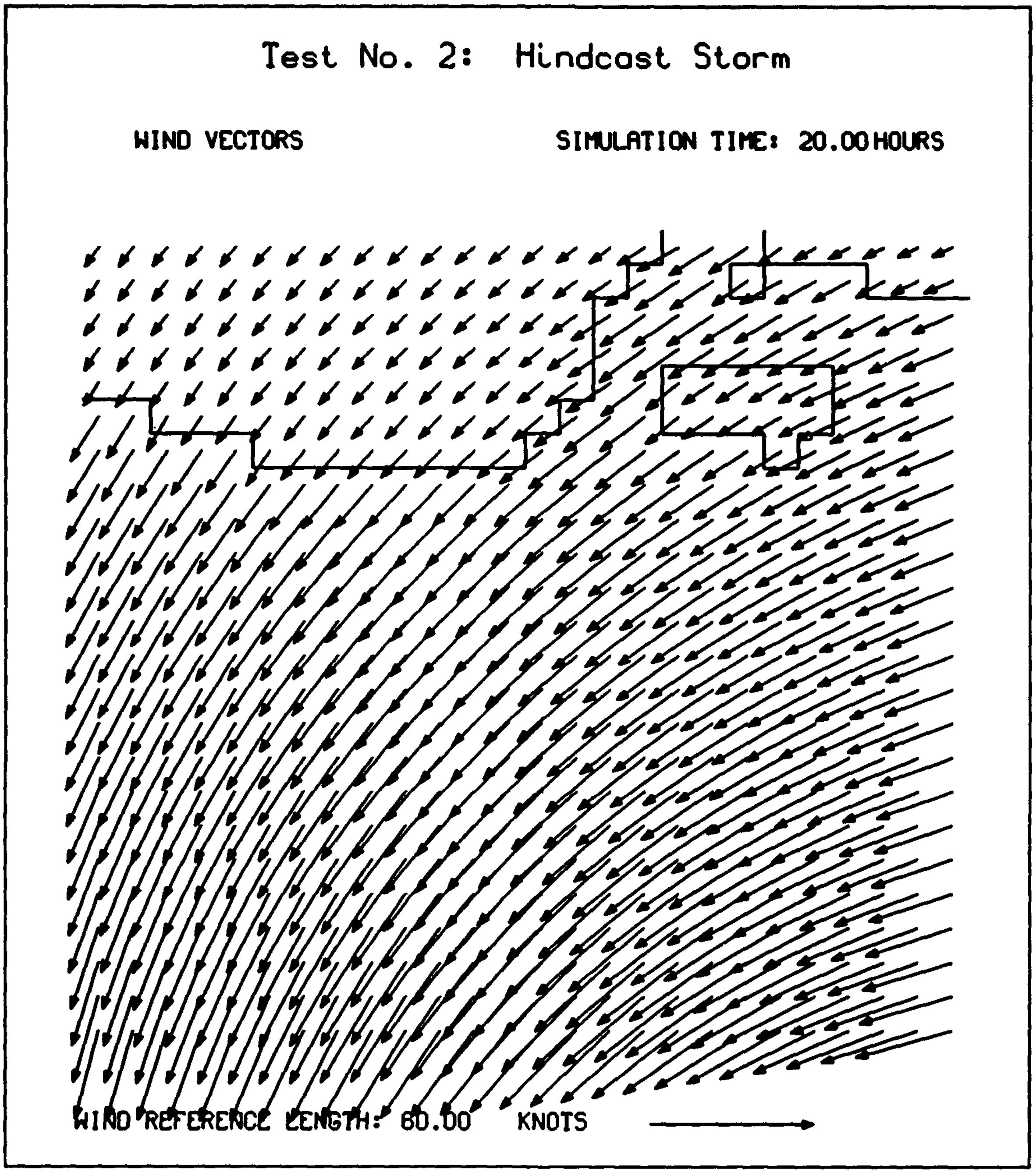


Figure 3-30. Test 2 wind-field snapshot at hour 20

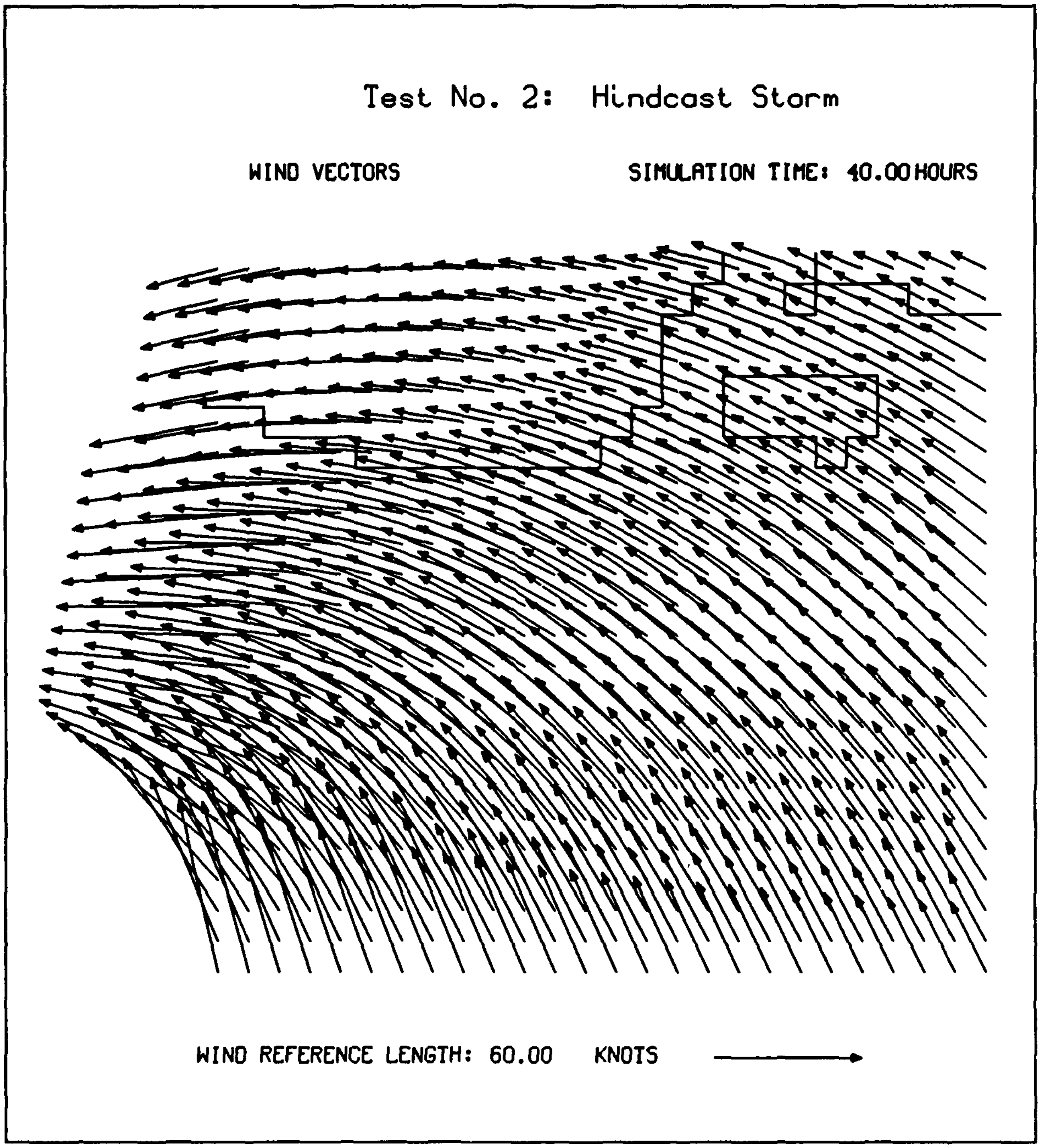


Figure 3-31. Test 2 wind-field snapshot at hour 40

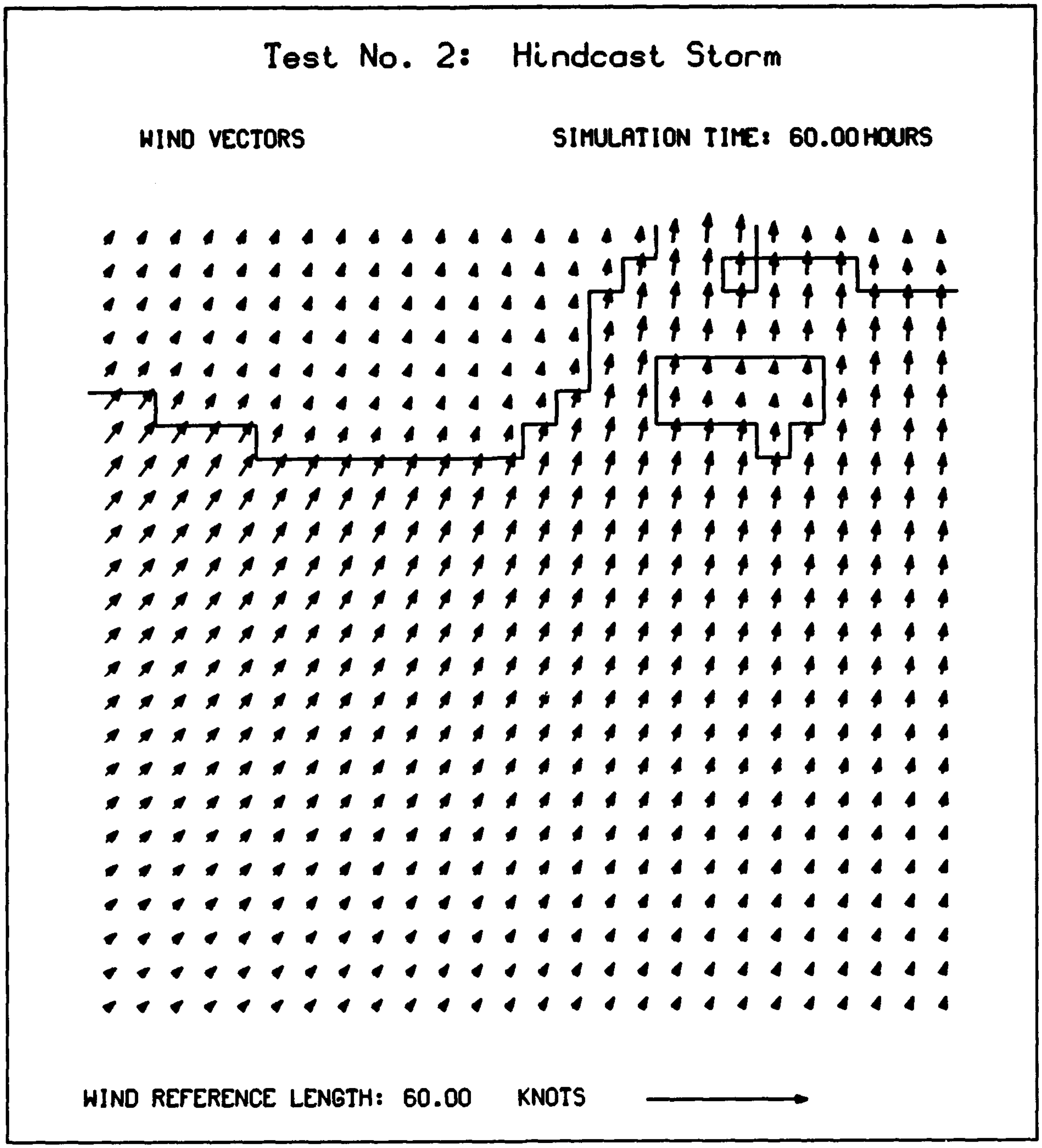


Figure 3-32. Test 2 wind-field snapshot at hour 60

Table 3-9

Input Data Summary for Test 2

---- Test No. 2: Hindcast Storm ----

***** GENSPEC CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*				

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		*	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	26		*	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	24	
DX	SPATIAL STEPSIZE IN X DIRECTION	38216.30		*	DY	SPATIAL STEPSIZE IN Y DIRECTION	38216.30	
GLATT	LATITUDE OF GRID ORIGIN (DEGREES)	28.48		*	GLONG	LONGITUDE OF GRID ORIGIN (DEGREES)	92.10	
GALIGN	GRID ROTATION FOR EAST (DEGREES)	340.00		*				

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (TUNITS)	900.0		*	TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	MINUTES	
TPROV	TIME AT START OF MODEL SIMULATION	0.0		*	TMAX	TOTAL TIME OF SIMULATION	3600.0	
DTGAGS	TIME INTERVAL TO SAVE GAGE DATA	15.00		*	DTHOTS	TIME INTERVAL TO SAVE HOTSTARTS	3600.00	

1 08/14/9111 C O A S T A L M O D E L I N G S Y S T E M (C M S) : S P H , V E R S I O N 1 . 0 :20:36

***** HYDROGRAPH AND VELOCITY MEASUREMENTS: 3 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	5	17		UAVGVAVG		SUBMERGED PIPE LOCATION
2	10	17		UAVGVAVG		DUMP SITE LOCATION
3	15	17		UAVGVAVG		MARSH ISLAND LOCATION

***** TIMES FOR SNAPSHOTS OF DATA SAVED (MINUTES):

600.000 1200.000 2400.000 3600.000

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER	*	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	*	TIMES TO PRINT (MINUTES): START AT	END AT	INTERVAL	NOTES:	*	VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1	*	X= 1	X= 26	Y= 1	Y= 24		*	0.0	3600.0	1.0		*	WP	

1 08/14/9111 C O A S T A L M O D E L I N G S Y S T E M (C M S) : S P H , V E R S I O N 1 . 0 :20:36

***** WINDSPEC CARD: SPECIFICATION OF THE WIND FIELD -

REFERENCES

Garcia, A. W., and Hegge, W. S. 1987. "Hurricane Danny Storm Surge Data," Technical Report CERC-87-11, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Myers, V. A. 1954. "Characteristics of United States Hurricanes Pertinent to Levee Design for the Lake Okeechobee, Florida," Hydrometeorological Report No. 32, US Weather Bureau, Department of Commerce and US Army Corps of Engineers, Washington, DC.

National Oceanic and Atmospheric Administration. 1979. "Meteorological Criteria for Standard Project Hurricane and Probable Maximum Hurricane Wind Fields, Gulf and East Coasts of the United States," Technical Report NWS 23, National Weather Service, Washington, DC.

Schloemer, R. W. 1954. "Analysis and Synthesis of Hurricane Wind Patterns over Lake Okeechobee, Florida," Hydoromet Report No. 31, Washington, DC.

APPENDIX 3-A: SPH DATA SPECIFICATION RECORDS

Model Control Specifications

(Req)	GENSPECS	Specify general title and system of units
(Req)	TIMESPEC	Specify time-related controlling variables

Grid Description

(Req)	GRIDSPEC	Specify general grid characteristics
(C-Opt)	XSTRETCH	Specify x-coordinates to create stretched grid
(C-Opt)	YSTRETCH	Specify y-coordinates to create stretched grid

Physical Characteristics

(Req)	BATHSPEC	Specify characteristics of bathymetry/topography
(Req)	--	Two-dimensional array of bathymetric/topographic data
(Opt)	CHNGBATH	Specify changes to the bathymetric/topographic data

Wind-Field Specifications

(Opt)	WINDSPEC	Specify the character of wind-field data
(C-Opt)	TABWINDS	Specify wind-field tabular data
(Req)	SPHSPEC	Specify general data for SPH wind model
(Req)	TABSPH	Specify SPH paramenters at a given time

Output Specifications

(Req)	PRWINDOW	Specify location and timing of a print window
(Opt)	RECGAGE	Specify location of recording gage in grid
(Opt)	RECSNAPS	Specify snapshot time(s) for recording

CMS Data Specification: GENSPECS Record: (Req)
Purpose: Specify general title and system of units.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		GENSPECS	Record identifier.
2-9	TITLE	Char *64	(Opt)		A*	General title for simulation.
10	SUNITS	Integer	(Opt)	ENGLISH	ENGLISH METRIC	Declares the system of units for computations and results.

Unit	English	Metric
Length	ft	m
Time	sec	sec
Velocity	ft/sec	m/sec
Discharge	cu ft/sec	cu m/sec
Pressure	ft (of water)	m (of water)

CMS Data Specification: TIMESPEC Record: (Req)
Purpose: Specify time-related controlling variables.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		TIMESPEC	Record identifier.
2	DELT	Real	(Req)		+R*	Time-step for simulation (seconds).
3	TUNITS	Char *8	(Opt)	HOURS	HOURS MINUTES SECONDS	Units for all time variables (except where noted).
4	TPROV	Real	(Opt)	0.	+R*	Provisional model time (in TUNITS) at start of simulation.
5	TMAX	Real	(Opt)	0.	+R*	Length of simulation (in TUNITS).
6	DTGAGS	Real	(Opt)	.25 hours	+R*	Time interval (in TUNITS) for recording time-history data (wind speeds, pressures).
7	DTHOTS (N/A to SPH)	Real	(Opt)	TMAX	+R*	Time interval (in TUNITS) for saving HOTSTART data.

CMS Data Specification: GRIDSPEC Record: (Req)
Purpose: Specify general computational grid characteristics.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		GRIDSPEC	Record identifier.
2	GRTYPE	Char *8	(Opt)	RECTANG	RECTANG	Cartesian system with constant-spaced grid cells.
					RSTRETCH	Cartesian system with stretching function employed to create grid cells. (requires XSTRETCH and YSTRETCH records after the GRIDSPEC)
3	GUNITS	Char *8	(Opt)	ENGLISH	ENGLISH METRIC	System of units for grid data.
4	XCELLS	Integer	(Req)		+I*	Number of grid cells in X-direction.
5	YCELLS	Integer	(Req)		+I*	Number of grid cells in Y-direction.
6	DX	Real	(Req)		+R*	Spatial stepsize in X-direction (in GUNITS).
7	DY	Real	(Req)		+R*	Spatial stepsize in Y-direction (in GUNITS).
8	GLATT	Real	(Req)		R*	Latitude of grid origin (decimal degrees).
9	GLONG	Real	(Req)		R*	Longitude of grid origin (decimal degrees).
10	GALIGN	Real	(Req)		R*	Grid alignment: specified as angle of X-axis (for Cartesian systems) measured counter-clockwise from east (decimal degrees).

CMS Data Specification: XSTRETCH and YSTRETCH Records: (C-opt)
Purpose: Specify the data to create grid coordinates in a stretched rectilinear Cartesian coordinate system.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		XSTRETCH YSTRETCH	Record identifier. (for X-coordinates) (for Y-coordinates)
2	ALPHAB	Integer	(Req)		I*	Alpha at beginning of grid subregion.
3	ALPHAE	Integer	(Req)		I*	Alpha at end of grid subregion.
4-5	A	Real	(Req)		R*	Stretching coefficients used to determine the X- and Y-coordinates in this grid subregion employing a power funtion of the form: X (or) Y = A + B * (ALPHA ** C)
6-7	B	Real	(Req)		R*	
8-9	C	Real	(Req)		R*	

Notes:
(1) Use one record per grid subregion (must be sequential..ie..Regionl, Reqion2...etc.).
(2) These records may be generated by MAPIT in the CMSGRID package.
(3) These records are required if RSTRETCH was specified for GRTYPE on GRIDSPEC record.
(4) A, B, and C use a special format: each should be G16.9 (occupies two fields).

CMS Data Specification: BATHSPEC Record: (Req)
Purpose: Specify general characteristics of the bathymetry/topography data.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		BATHSPEC	Record identifier.
2	BUNITS	Char *8	(Opt)	FEET	FEET METERS FATHOMS	Declares the units for the following bathymetry/topography data
3	WDATUM	Real	(Opt)	0.	R*	Negative values of bathymetry (depths) are added to this datum value (in BUNITS)
4	LDATUM	Real	(Opt)	0.	R*	Positive values of topography are added to this datum (in BUNITS).
5	DLIMIT	Real	(Opt)	-6000. ft	R*	A limiting water depth (deeper values are set to this value in BUNITS).
6	BSEQ	Char *8	(Opt)	XY	XY -XY X-Y -X-Y YX -YX Y-X -Y-X	The 2-D array of bathymetry/topography that follows this record is read in a sequence specified by this mnemonic code (see Table 3-4 for the conventions represented by these mnemonics).
7-8	BFORM	Char *16	(Opt)	(8G10.3)	A*	Format used to read the following 2-D arr. · of bathymetry/topography values.
9-10	BNAME	Char *16	(Opt)		A*	Name of bathymetry/topography set.

Notes:
(1) The actual 2-D array of bathymetry/topography data follows this record.
(2) Conventions for 2-D array read sequence mnemonics:

(Continued)

(Concluded)

```
****************** SEQ - XY *******************
        DO 1 J-1,YCELLS
    1   READ(LUN,FORM) (VAR(I,J),I-1,XCELLS)

***************** SEQ - -XY *******************
        DO 2 J-1,YCELLS
    2   READ(LUN,FORM) (VAR(I,J),I-XCELLS,1,-1)

***************** SEQ - X-Y *******************
        DO 3 J-YCELLS,1,-1
    3   READ(LUN,FORM) (VAR(I,J),I-1,XCELLS)

***************** SEQ --X-Y *******************
        DO 4 J-YCELLS,1,-1
    4   READ(LUN,FORM) (VAR(I,J),I-XCELLS,1,-1)

***************** SEQ - YX ********************
        DO 5 I-1,XCELLS
    5   READ(LUN,FORM) (VAR(I,J),J-1,YCELLS)

***************** SEQ - -YX *******************
        DO 6 I-1,XCELLS
    6   READ(LUN,FORM) (VAR(I,J),J-YCELLS,1,-1)

***************** SEQ - Y-X *******************
        DO 7 I-XCELLS,1,-1
    7   READ(LUN,FORM) (VAR(I,J),J-1,YCELLS)

**************** SEQ - -Y-X *******************
        DO 8 I-XCELLS,1,-1
    8   READ(LUN,FORM) (VAR(I,J),J-YCELLS,1,-1)
```

CMS Data Specification: CHNGBATH Record: (Opt)
Purpose: Specify changes to the bathymetry data.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		CHNGBATH	Record identifier.
2	BATH	Real	(Req)		R*	New bathymetry/topography value (in BUNITS ... the two datum shift values LDATUM and WDATUM will not be applied to this value).
3	X1INDX	Integer	(Req)		I*	Declares the location of the bathymetry /topography value as a point, line, or a rectangular patch in the grid.
4	Y1INDX	Integer	(Req)		I*	
5	X2INDX	Integer	(Opt)	0	I*	
6	Y2INDX	Integer	(Opt)	0	I*	

Note:
(1) Use one CHNGBATH record per value (no changes if this record is omitted).
(2) All CHNGBATH records must follow the two-dimensional bathymetry array.

CMS Data Specification: WINDSPEC Record: (Req)
Purpose: Specify the character of wind-field data.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		WINDSPEC	Record identifier.
2	WTYPE	Char *8	(Opt)	SPH	SPH	SPH wind-field model used in simulation.
3	WNTRVL	Char *8	(Opt)		CONSTANT	This implies a constant translation *storm. One TABSPH record should follow* this record.
					VARIABLE	This implies a variable translation storm. Several TABSPH records might follow this record.
4	WUNITS	Char *8	(Opt)	FPS	MPH FPS MPS KNOTS	Units for wind input values.
5	PUNITS	Char *8	(Opt)	FEETH20	MILLIBAR FEETH2O METERH2O PSI INCHESHG MMHG	Units for atmospheric pressure input. (Feet of water) (Meters of water) (Pounds/square inch) (Inches of mercury) (millimeters of mercury)
6	WINTRP	Real	(Opt)	0.	+R*	Time interval (in TUNITS) to interpolate wind field from given values.
7	WFETHR	Real	(Opt)	0.	+R*	The wind field is gradually spline fit from quiescent conditions to the given (or interpolated) value over the WFETHR period (in TUNITS).

(Continued)

(Concluded)

8-10	WNAME	Char *24	(Opt)	A*	Wind event name.

Note: No winds are applied to the model if this record is omitted.

CMS Data Specification: SPHSPEC Record: (Req)
Purpose: Specify general data to be employed by an SPH wind-field model.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		SPHSPEC	Record identifier.
2	PRFPRS	Real	(Req)		+R*	Atmospheric pressure at periphery of storm (in PUNITS).
3	RMAXE	Real	(Req)		+R*	Effective radius parameter (a form factor that adjusts the radial wind-field distribution.
4	SPHDLT	Real	(C-opt)		R*	Time between wind-field computations (applies to constant translation *storms only* .... in TUNITS).
5	HTRACK	Real	(C-opt)		R*	Direction of storm movement (applies to constant translation storms only ... in decimal degrees).
6	VTRANS	Real	(C-opt)		R*	Forward speed of storm (applies to *constant translation storms* only). in WUNITS

CMS Data Specification: TABSPH Record: (Req)
Purpose: Specify the SPH parameters at a given time.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		TABSPH	Record identifier.
2	SPHOUR	Real	(Req)		R*	Hour at which these SPH parameters occur (hours).
3	SPHMIN	Real	(Req)		R*	Minute at which these SPH parameters occur (minutes).
4	SPHLAT	Real	(Req)		R*	For constant translation storms: Latitude of storm eye at landfall. For variable translation storms: Latitude of storm eye at above time denoted by SPHOUR AND SPHMIN. (decimal degrees)
5	SPHLNG	Real	(Req)		R*	For constant translation storms: Longitude of storm eye at landfall. For variable translation storms: Longitude of storm eye at above time denoted by SPHOUR AND SPHMIN. (decimal degrees)
6	CPI	Real	(Req)		+R*	Central pressure index (in PUNITS).
7	RMAX	Real	(Req)		+R*	Radius to maximum winds. (nautical miles)
8	MAXWND	Real	(Req)		+R*	Maximum wind speed (in WUNITS).
9	AZMUTH	Real	(Req)		R*	Angle to maximum winds (decimal degrees).
10	NGRESS	Real	(Req)		R*	Wind inflow angle (decimal degrees).

Notes:
(1) At least one TABSPH record must follow an SPHSPEC record.
(2) Use one TABSPH record for each time entry to describe the variable translation storm.

CMS Data Specification: PRWINDOW Record: (Opt)

Purpose: Specify location and timing of a print window.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		PRWINDOW	Record identifier.
2	WXCEL1	Integer	(Opt)	1	+I*	Cell indices declaring the grid subregion or window for printing the selected variables. The window will be bounded by (and include) the region from (WXCEL1,WYCEL1) to (WXCEL2,WYCEL2).
3	WXCEL2	Integer	(Opt)	XCELLS	+I*	
4	WYCEL1	Integer	(Opt)	1	+I*	
5	WYCEL2	Integer	(Opt)	YCELLS	+I*	
6	WPRINT	Real	(Opt)	1.0 (HR)	+R*	Time interval (in TUNITS) at which the print window is to be recorded.
7	WPRSTR	Real	(Opt)	0.	+R*	Time (in TUNITS) at which print window is to begin recording.
8	WPREND	Real	(Opt)	TMAX	+R*	Time (in TUNITS) at which print window is to end recording.
9-10	WPRVAR	Char *16	(Opt)	WP	E	Water surface elevations.
					V	Water velocities (two components).
					W	Wind velocities (two components).
					B	Bathymetry value.
					D	Depth of water column.
					F	Friction value.

(Continued)

(Concluded)

T	E and V at previous time-step (three values).
S	Status flags.
P	Pressure anomaly

Note: only W, B, and P are applicable for model SPH

Note: Use 1 PRWINDOW record per window (in space or time).

CMS Data Specification: RECGAGE Record: (Opt)
Purpose: Specify location and character of a recording gage in the grid.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		RECGAGE	Record identifier.
2	GXPOS	Integer	(Req)		+I*	X-index of gage location within grid.
3	GYPOS	Integer	(Req)		+I*	Y-index of gage location within grid.
4	GTYPE	Char *8	(Opt)	UavgVavg	UavgVavg UavgV UVavg UV U V Uavg Vavg	Methods of computing the velocity recorded at this gage (WIFM applications only).
5-10	GNAME	Char *45	(Opt)		A*	Gage name.

Notes:
(1) Use one RECGAGE record per gage.
(2) The interval for recording all gage data was specified by DTGAGE on the TIMESPEC record.
(3) Variable GTYPE is only applicable to averaging water velocities generated by WIFM and does not affect output from model SPH.

CMS Data Specification: RECSNAPS Record: (Opt)
Purpose: Specify snapshot time(s) for recording.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		RECSNAPS	Record identifier.
2	SNPTYP	Char *8	(Req)		INTERVAL	Snapshot data to be recorded at regular time intervals.
3	SNPINT	Real	(Opt)	1.0 (hr)	+R*	Regular time interval (in TUNITS) at which snapshot data are to be recorded.
4	SNPSTR	Real	(Opt)	0.	+R*	Time (in TUNITS) at which snapshot recording is to begin.
5	SNPEND	Real	(Opt)	TMAX	+R*	Time (in TUNITS) at which snapshot recording is to end.

Alternate form for specific times

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		RECSNAPS	Record identifier.
2	SNPTYP	Char *8	(Req)		TIMES	Snapshot data to be recorded at specific times (which follow on this record in fields 3-10).
3-10	SNPTIM	Real	(Req)		+R*	Time (in TUNITS) at which a snapshot is to be recorded (one SNPTIM per field in fields 3-10). Use additional records of this format if more than eight specific times are required.

Notes:
(1) Any number of both types of snapshot records may be specified.
(2) Times specified must be integer multiples of DELT.

CHAPTER 4

WES IMPLICIT FLOODING MODEL (WIFM)

THEORY AND PROGRAM DOCUMENTATION

PART I: INTRODUCTION

1. Use of time-dependent numerical models for simulating long-period wave behavior in open coastal waters, estuaries, bays, and lakes has increased rapidly in recent years. Two- and three-dimensional numerical solutions of the governing partial differential equations are employed in most shallow-water long-wave applications. This chapter documents the WES Implicit Flooding Model (WIFM), a two-dimensional, depth-integrated model for computing tidal circulation and storm surge propagation. The model was originally developed at WES (Butler 1978a) and has evolved as it has been applied to problems involving simulation of long-period wave behavior (Butler 1978b). Successful applications of the model include simulations of tidal circulation (Butler 1978a, Butler 1983), storm surge (Butler 1984, Hardy and Crawford 1986), and tsunami inundation (Houston and Garcia 1974).

2. WIFM is a two-dimensional model; therefore, velocities are treated as depth-integrated quantities (i.e., velocities are constant in magnitude and direction over depth). The model solves finite difference approximations of the Navier-Stokes (continuity and horizontal momentum) equations for the water surface displacement (η) and the vertically integrated velocities (u and v). The basic implicit solution schemes used in WIFM were developed by Leendertse (1967, 1970, 1971) and Weare (1980). The treatment of flooding/drying is original in WIFM, whereas the handling of subgrid barriers follows the procedures presented in Reid and Bodine (1968). WIFM can simulate flow fields induced by wind, river inflows/outflows, and tidal forcing.

3. A thorough understanding of the model's capabilities and limitations prior to any attempt to apply it, is essential. WIFM is not a "total solution" to a hydrodynamic problem. The user must ensure that limitations imposed by shallow-water wave theory (i.e., water depth is sufficiently small when compared with wavelength) are applicable to the problem being investigated. Furthermore, the model should not be treated as a "black box"; the engineer or scientist must check model results to see if these results are reasonable.

4. This chapter is divided into five sections: Part II presents the governing equations and computational scheme used in the model, Part III defines the input data formats, Part IV discusses the model's input data requirements, and Part V contains two illustrative examples.

PART II: SHALLOW-WATER WAVE EQUATIONS

Assumptions and Limitations

5. Proper application of any model requires a clear understanding of the physical processes occurring in a study area and a comprehension of the capabilities of a given model to simulate those processes. Model results should provide a realistic representation of the physical system being modeled.

6. The limitations of a model define its range of applicability. In particular, WIFM is a two-dimensional depth-integrated model; therefore, the model should be applied only where the water column is well mixed and no significant vertical variations occur. The model should not be applied if temperature and/or salinity gradients have an appreciable effect on fluid motion as compared with external forces. In addition, hydrostatic pressure conditions are assumed in the model formulation. Thus, the model should be applied only where there is no significant vertical acceleration of the water such as what might occur near an outlet structure. Applying WIFM requires a clear understanding of the model's capabilities, as well as its limitations. WIFM can simulate flow fields induced by wind fields, river inflows/outflows, and tidal forcing. The model is capable of flooding and drying grid cells and simulates submerged, exposed, or overtopping barriers.

7. The model should be applied such that time and length scales associated with long-wave processes can be resolved. The minimum wavelength that can be resolved by the model is equal to twice the width of the smallest grid cell; however, wavelengths used in long-wave models are much greater than the minimum resolvable wavelength. Since shallow-water wave theory is only valid where the water depth is small in relation to the wavelength ($d/L < 0.04$), the minimum wavelength must be greater than or equal to 25 times the deepest water depth. These constraints indicate the importance of careful selection of the length scale.

8. The length scale/time scale ratio must be of the same order of magnitude as the shallow-water wave celerity in order to reproduce wave propagation accurately. The model must be able to resolve a fluid particle moving from one cell to the next. Since the travel time of that particle is dependent on the cell width as well as the wave celerity, the time interval

between successive numerical solutions of the governing equations must be chosen carefully. The Courant number, C_r , defines the relationship of wave celerity and grid speed:

$$C_r = \frac{\sqrt{gh}}{\Delta x/\Delta t} \tag{4-1}$$

where

- g = gravitational acceleration
- h = water depth
- Δx = grid cell width in the direction of wave propagation
- Δt = time interval between successive calculations

For the Alternatin Direction Implicit (ADI) scheme used in WIFM, the Courant number should usua__y be less than a value of 5. Larger values of the Courant number may be permissible at a distance from the area of interest within the computational domain; however, numerical accuracy will be affected.

9. A thorough comprehension of the physical processes simulated by the model is necessary to ensure that the model is applied to appropriate problems, that it is applied correctly, and that accurate results are produced. A discussion of the hydrodynamic equations used in WIFM is provided in the following section. It is recommended that the reader refer to Horikawa (1988) for a detailed discussion of coastal hydrodynamics.

Governing Equations

10. The hydrodynamic equations used in WIFM are derived from the classical Navier-Stokes equations formulated in a Cartesian coordinate system (Figure 4-1). If the vertical water accelerations are assumed to be small compared with the gravitational acceleration (hydrostatic pressure conditions exist) and the fluid is homogeneous and incompressible, the depth-averaged approximation is appropriate and yields the following two-dimensional form of the governing equations:

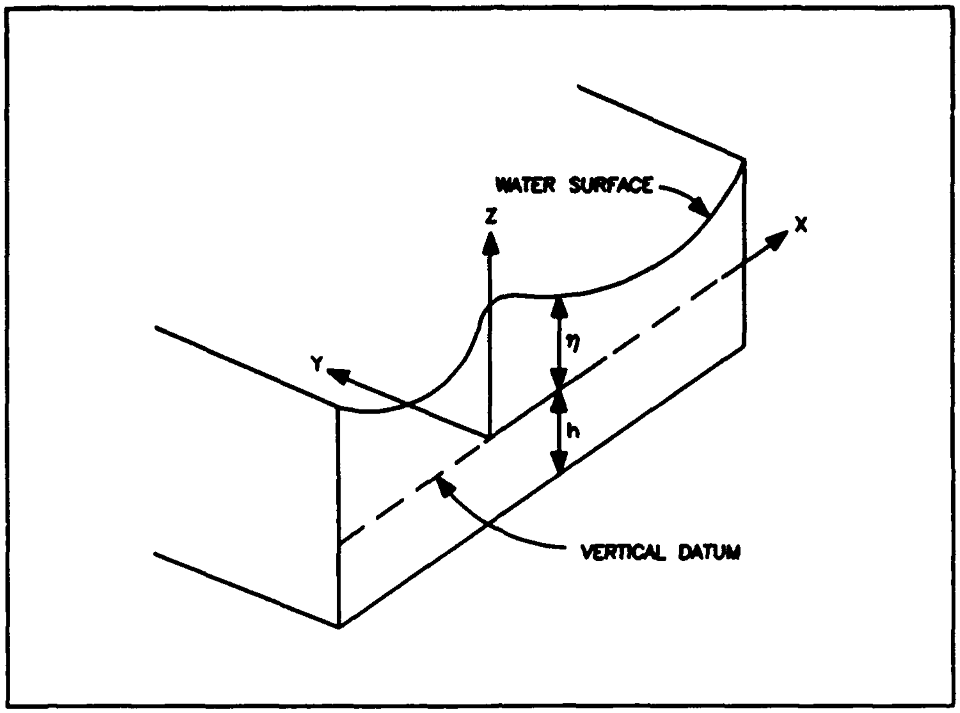


Figure 4-1. Cartesian coordinate system

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial}{\partial x}(\eta - \eta_a) - fv - \frac{\tau_{sx}}{\rho d} + \frac{\tau_{Bx}}{\rho d} + A_H\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) = 0 \quad (4\text{-}2)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g\frac{\partial}{\partial y}(\eta - \eta_a) + fu - \frac{\tau_{sy}}{\rho d} + \frac{\tau_{By}}{\rho d} + A_H\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) = 0 \quad (4\text{-}3)$$

$$\frac{\partial \eta}{\partial t} + \frac{\partial}{\partial x}(ud) + \frac{\partial}{\partial y}(vd) = R \quad (4\text{-}4)$$

I II III IV V VI

where

x, y, t - independent space and time variables

η - water surface displacement measured relative to an arbitrary datum

η_a - water surface displacement due to the atmospheric pressure anomaly

h - static water depth measured from the same datum

d - total water depth ($h + \eta$)

u, v - velocity components in the x- and y-directions, respectively

τ_{Bx} , τ_{By} = bottom friction stresses in the x-and y-directions, respectively

f = Coriolis parameter

A_H = generalized diffusion coefficient

g = gravitational acceleration

τ_{sx}, τ_{sy} = external surface shear stresses, such as wind stress, in the x-and y-directions, respectively

ρ = water density

R = source/sink term to account for mass changes such as rainfall, percolation, etc.

Equations 4-2, 4-3 and 4-4 represent the nonconservative form of the x-momentum, y-momentum, and continuity equations, respectively. The model is capable of using the conservative form of Equations 4-2 through 4-4 as well.

11. A detailed discussion of the Navier-Stokes equations with a rigorous derivative of each term is found in Harris and Bodine (1977). A brief discussion of the physical significance of the six groups of terms in Equations 4-2 through 4-4 is given below and in Table 4-1. The Roman numerals below correspond to the Roman numerals in Equations 4-2 through 4-4:

I. Local flow acceleration (i.e., local variation of momentum with respect to time).

II. Transport of momentum by advection (i.e., spatial acceleration).

III. Barotropic pressure forces and conservation of mass.

IV. Momentum sources and sinks due to Coriolis force and surface wind stress.

V. Momentum sink due to bed friction.

VI. Horizontal diffusion of momentum.

Table 4-1

Description of Terms in the Governing Equations

Term	Definition and Discussion
$\frac{\partial u}{\partial t}, \frac{\partial v}{\partial t}$	Change of the vertically averaged velocity with respect to time. Change may result from temporal acceleration of the mean flow.
$g\frac{\partial}{\partial x}(\eta - \eta_a)$	Pressure gradient terms; describes the slope of the water surface; principal driving force of fluid flow.
τ_{Bx}, τ_{By}	Bottom friction terms; stress of the fluid layer against the bottom boundary; serves as an energy dissipator.
fu, fv	Coriolis terms; accounts for the effect of the Earth's rotation.
$u\frac{\partial u}{\partial x}$	Inertia (advective) terms; describes the movement of water due to the fluid motion itself.
τ_{sx}, τ_{sy}	External shear stresses (such as the wind); any forcing function that serves to drive the fluid motion.
$A_H\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right)$	Horizontal diffusion of momentum; describes the dispersion of momentum due to fluid motion; A_H is sometimes referred to as the eddy viscosity.
$\frac{\partial \eta}{\partial t}$	Change in water level with respect to time.
$\frac{\partial}{\partial x}(ud)$	Rate at which water is converging or diverging horizontally at a given point (x,y) in space.
R	Sink/Source term that accounts for mass changes (i.e. rainfall, percolation).

12. Various formulations of the terms in the governing equations are permissible. The expressions for bottom friction, diffusion, wind stress, and the Coriolis coefficient employed in WIFM are as follows:

Bottom friction

13. The bottom shear stress impeding fluid motion in unidirectional open channel flow can be expressed in terms of a quadratic (nonlinear) friction law:

$$\tau_B = \frac{\rho f u^2}{8} \tag{4-5}$$

where

ρ = fluid density

f = Darcy-Weisbach friction factor

u = fluid velocity

The importance of the direction of the velocity in oscillatory flow means that Equation 4-5 must contain an absolute value sign:

$$\tau_B = \frac{\rho f u|u|}{8} \tag{4-6}$$

14. WIFM uses the following quadratic expressions to represent the bottom shear stress in the x-momentum equation:

$$\frac{\tau_{Bx}}{\rho} = \frac{gu}{C_z^2 d}(u^2 + v^2)^{1/2} \tag{4-7}$$

where

ρ = fluid density

g = gravitational acceleration

C_z = Chezy's friction coefficient

d = water depth

u, v = velocity components in the x-and y-directions, respectively.

A similar expression is used for τ_{By} in the y-momentum equation.

15. Rather than specifying the Chezy coefficient, Manning's n, which is a function of depth, is often prescribed (Chow 1959). The two coefficients are related through the following equation:

$$C_z = \frac{d^{1/6}}{n} \tag{4-8}$$

WIFM uses a spatially variable drag coefficient, n . The advantage of a variable drag coefficient is that variation in depth can be factored into bottom shear stress computations.

Diffusion coefficient

16. The diffusion (or eddy viscosity) coefficient, A_H , can be treated as variable or constant in WIFM and describes the rate of diffusion of momentum due to the fluid motion. Variable A_H is formulated by Vreugdenhil (1973) as

$$A_H = \frac{6d\,[g\,(u^2 + v^2)^{1/2}]}{C_z} \tag{4-9}$$

where

d = total water depth

g = gravitational acceleration

u, v = vertically integrated velocity components

C_z = Chezy coefficient

Constant A_H usually ranges from 5 to 20 (English) or 0.5 to 2.0 (metric).

Wind stress coefficient

17. The wind stress, τ_s , is formulated as:

$$\tau_s = \rho_a C_D |W| W \tag{4-10}$$

where ρ_a is the air density, W is the wind velocity, C_D is the wind drag coefficient determined from Garratt's equation (Garratt 1977):

$$C_D = \frac{(0.75 + 0.067\omega)}{1000} \tag{4-11}$$

and ω is the resultant wind speed (meters/second). The wind velocity, W , and the wind stress, τ_s , are converted by the model and need not be given in metric units.

Coriolis coefficient

18. The Coriolis term accounts for the fact that the Earth is rotating, whereas the coordinate frame of our computations is fixed. The Coriolis parameter, f , is expressed as:

$$f = 2\nu \sin\lambda \tag{4-12}$$

where ν is the angular speed of the Earth's rotation (7.292×10^{-5} rad/sec) and λ is the latitude of the study area.

19. This completes the basic model formulation. If further details of the governing equations are necessary, the reader should refer to Horikawa (1988).

Grid System

20. The governing equations (Equations 4-2, 4-3, and 4-4) which describe the physical processes associated with shallow-water wave motion contain partial derivatives with respect to time and space. WIFM uses mathematical (finite difference) approximations to represent these continuous equations. The continuum is, therefore, represented by discrete points in time and space. The discretization of the horizontal plane is accomplished via a computational grid composed of a lattice network of cells. Each cell has certain flow field parameters associated with it. In the case of WIFM, the water surface elevation is defined at the center of each cell, and the vertically averaged velocity components are defined at the cell faces. All information required as input to the model, including water depths and external forces (such as wind), is defined at each grid cell.

21. WIFM is capable of using a uniform or stretched Cartesian grid. Uniform Cartesian grids simply have cells of equal size in the x-direction and equal size in the y-direction (Figure 4-2). A major advantage of WIFM is the capability of applying a smoothly varying (stretched) grid to a given study region (Figure 4-3). This capability permits simulation of complex geometry by locally increasing grid resolution. This feature is accomplished by independently applying a piecewise reversible transformation for each direction (analogous to that used by Wanstrath et al. 1976) to map prototype or real space (x,y) into computational space (α_1,α_2).

22. The transformation in each piece of the grid takes the form of:

$$x = a + b\alpha^c \quad (4\text{-}13)$$

where a , b , and c are arbitrary constants. The transformation is such that cells are uniformly spaced in computational space; therefore, all derivatives are centered in computational space. Many stability problems commonly associated with variably spaced grid schemes are eliminated via the smoothness of the transformation procedure. The transformed equations of motion are presented in the following:

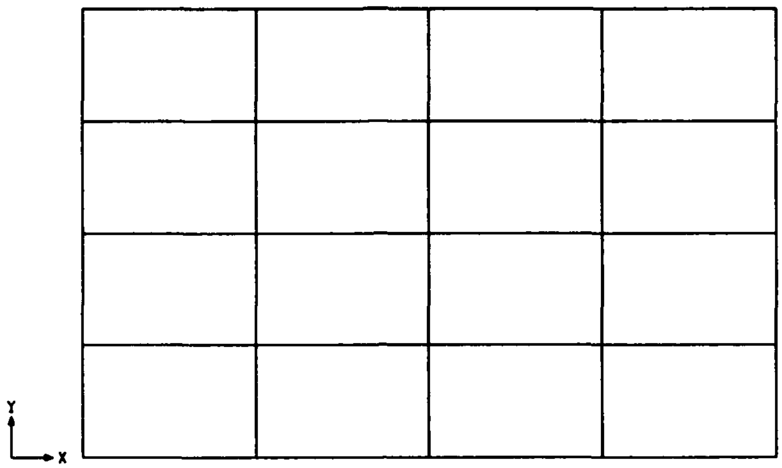


Figure 4-2. Uniform Cartesian grid

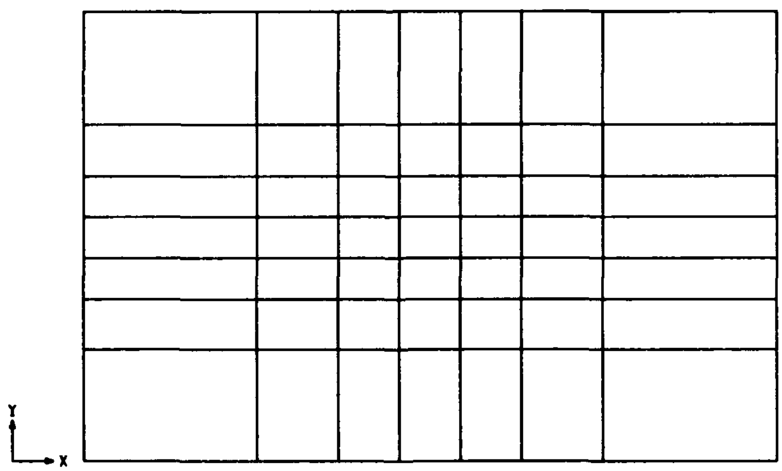


Figure 4-3. Stretched Cartesian grid

X-momentum

$$u_t + \frac{1}{\mu_1} u u_{\alpha_1} + \frac{1}{\mu_2} v u_{\alpha_2} + \frac{g}{\mu_1} (\eta - \eta_a)_{\alpha_1} - f v - \frac{\tau_{s\alpha_1}}{\rho d} + \frac{\tau_{B\alpha_1}}{\rho d} \tag{4-14}$$

$$+ A_H \left(\left(\frac{1}{\mu_1}\right)^2 \mu_{\alpha_1\alpha_1} + \frac{1}{\mu_1}\left(\frac{1}{\mu_1}\right)_{\alpha_1} u_{\alpha_1} + \left(\frac{1}{\mu_2}\right)^2 u_{\alpha_2\alpha_2} + \frac{1}{\mu_2}\left(\frac{1}{\mu_2}\right)_{\alpha_2} u_{\alpha_2} \right) = 0$$

Y-momentum

$$v_t + \frac{1}{\mu_1} u v_{\alpha_1} + \frac{1}{\mu_2} v v_{\alpha_2} + \frac{g}{\mu_2} (\eta - \eta_a)_{\alpha_2} + f u - \frac{\tau_{s\alpha_2}}{\rho d} + \frac{\tau_{B\alpha_2}}{\rho d} \tag{4-15}$$

$$+ A_H \left(\left(\frac{1}{\mu_1}\right)^2 v_{\alpha_1\alpha_1} + \frac{1}{\mu_1}\left(\frac{1}{\mu_1}\right)_{\alpha_1} v_{\alpha_1} + \left(\frac{1}{\mu_2}\right)^2 v_{\alpha_2\alpha_2} + \frac{1}{\mu_2}\left(\frac{1}{\mu_2}\right)_{\alpha_2} v_{\alpha_2} \right) = 0$$

Continuity

$$n_t + \frac{1}{\mu_1} (du)_{\alpha_1} + \frac{1}{\mu_2} (dv)_{\alpha_2} = R \tag{4-16}$$

where $\quad \mu_1 = \dfrac{\partial x}{\partial \alpha_1} = b_1 c_1 \alpha^{c_1 - 1}$ *and* $\mu_2 = \dfrac{\partial y}{\partial \alpha_2} = b_2 c_2 \alpha^{c_2 - 1}$

Computational Technique

23. Since analytical solutions of the governing equations have been determined only for very simple situations, discrete approximations of the governing equations are required to produce a general purpose model solution. This is accomplished by evaluating the derivatives in the governing equations with finite difference approximations.

24. The finite difference approximations incorporated in WIFM are based on an Eulerian system where the velocities and water surface fluctuations are computed at discrete locations within the flow field. A network of grid cells

is used to define the spatial distribution of these parameter locations. A representative grid cell is shown in Figure 4-4. The water surface fluctuations are solved at the cell center (i.e., node i,j). X-direction velocities, u, are found at the "west" and "east" cell faces, nodes (i-1,j) and (i,j) respectively, while the y-direction velocities, v, are computed at the "south" and "north" faces, nodes (i,j-1) and (i,j), respectively. The finite difference equations used in WIFM are as follows:

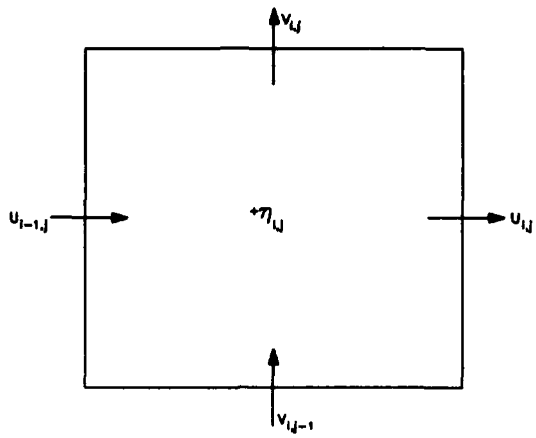


Figure 4-4. Representative grid cell

X-momentum

$$\frac{1}{2\Delta t}\left(u^{k+1} - u^{k-1}\right) + \frac{1}{2\mu_1 \Delta\alpha_1} u^k \delta_{2\alpha_1}\left(u^k\right) + \frac{1}{2\mu_2 \Delta\alpha_2} \bar{\bar{v}}^k \delta_{2\alpha_2}\left(u^k\right) \tag{4-17}$$

$$+ \frac{g}{2\mu_1 \Delta\alpha_1}\left[\delta_{\alpha_1}\left(\eta^* + \eta^{k-1} - 2\eta_s^k\right)\right] - f\bar{\bar{v}}^k - \frac{\tau_{s\alpha_1}^k}{\rho d} + \frac{g}{(C_z^2 d)^k} u^{k+1}\left[\left(u^{k-1}\right)^2 + \left(\bar{\bar{v}}^{k-1}\right)^2\right]^{1/2}$$

$$+ A_H\left[\frac{1}{(\mu_1 \Delta\alpha_1)^2}\delta_{\alpha_1\alpha_1}\left(u^k\right) + \frac{1}{(\mu_2 \Delta\alpha_2)^2}\delta_{\alpha_2\alpha_2}\left(u^k\right) + \frac{1}{2\mu_1 \Delta\alpha_1^2}\delta_{\alpha_1}\left(\frac{1}{\mu_1}\right)\delta_{2\alpha_1}\left(u^k\right)\right.$$

$$\left. + \frac{1}{2\mu_2 \Delta\alpha_2^2}\delta_{\alpha_2}\left(\frac{1}{\mu_2}\right)\delta_{2\alpha_2}\left(u^k\right)\right] = 0$$

Y-momentum

$$\frac{1}{2\Delta t}(v^{k+1} - v^{k-1}) + \frac{1}{2\mu_1\Delta\alpha_1}\bar{\bar{u}}^k \delta_{2\alpha_1}(v^k) + \frac{1}{2\mu_2\Delta\alpha_2} v^k \delta_{2\alpha_2}(v^k) \tag{4-18}$$

$$+ \frac{g}{2\mu_2\Delta\alpha_2}\left[\delta_{\alpha_2}(\eta^* + \eta^{k-1} - 2\eta_a^k) + f\bar{\bar{u}}^k - \frac{\tau_{s\alpha_2}^k}{\rho d} + \frac{g}{(C_z^2 d)^k} v^{k+1}[(\bar{\bar{u}}^{k-1})^2 + (v^{k-1})^2]^{1/2}\right.$$

$$+ A_H\left[\frac{1}{(\mu_1\Delta\alpha_1)^2}\delta_{\alpha_1\alpha_1}(v^k) + \frac{1}{(\mu_2\Delta\alpha_2)^2}\delta_{\alpha_2\alpha_2}(v^k) + \frac{1}{2\mu_1\Delta\alpha_1^2}\delta_{\alpha_1}\left(\frac{1}{\mu_1}\right)\delta_{2\alpha_1}(v^k)\right]$$

$$\left. + \frac{1}{2\mu_2\Delta\alpha_2^2}\delta_{\alpha_2}\left(\frac{1}{\mu_2}\right)\delta_{2\alpha_2}(v^k)\right] = 0$$

X-Continuity

$$\frac{1}{2\Delta t}(\eta^* - \eta^{k-1}) + \frac{1}{2\mu_1\Delta\alpha_1}[\delta_{\alpha_1}(u^{k+1}d^k + u^{k-1}d^k)] + \frac{1}{\mu_2\Delta\alpha_2}\delta_{\alpha_2}(v^{k-1}d^k) = R^k \tag{4-19}$$

Y-Continuity

$$\frac{1}{2\Delta t}(\eta^{k+1} - \eta^*) + \frac{1}{2\mu_2\Delta\alpha_2}\delta_{\alpha_2}(v^{k+1}d^k - v^{k-1}d^k) = 0 \tag{4-20}$$

where

$\delta_\alpha(Z) = Z_{\alpha+\frac{1}{2}} - Z_{\alpha-\frac{1}{2}}$

$\delta_{2\alpha}(Z) = Z_{\alpha+1} - Z_{\alpha-1}$

$\delta_{\alpha\alpha}(Z) = Z_{\alpha+1} - 2Z_\alpha + Z_{\alpha-1}$

k = time level

$*$ = intermediate time level

$-$ = spatially averaged quantity (u at a v-face, v at a u-face)

25. The computational procedure used in WIFM to solve the finite difference equations is based on an ADI method. The advantage of this method is

that it allows the x-continuity and momentum and y-continuity and momentum approximations to be solved separately, thus permitting the flow calculations to be made in two stages (Figure 4-5).

26. The first stage consists of sequentially solving the x-continuity and x-momentum equations along each row in the grid. The x-momentum equations are centered about the cell faces and are solved for the *u*-velocities. The x-continuity equations are centered about the cell centers and are solved for the surface fluctuations. The *u*-velocities and surface fluctuations are solved implicitly, while the y-direction velocities are supplied from time levels k and $k-1$. The *u*-velocities represent those at time level $k+1$; however, the surface fluctuations, η^* , are an approximation to those at time level $k+1$.

27. The second stage involves sequentially solving the y-continuity and y-momentum equations along each column in the grid to obtain the *v*-velocities and water surface fluctuations at time level $k+1$. *U*-velocities are provided from time levels $k-1$ and k.

28. Solving the finite difference approximations by a fully implicit scheme requires a relatively large quantity of computer resources. A more economical, although less accurate, calculation method is to use a tridiagonal matrix solution scheme. WIFM employs a three-time-level "leapfrog" scheme to solve the tridiagonal matrix solution. That is, at time level k, we use information from time level $k-1$ and leap forward in time to a solution at time level $k+1$.

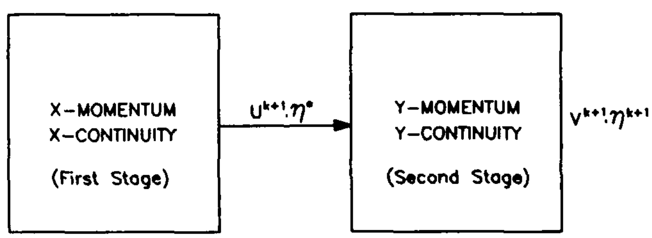


Figure 4-5. Computational procedure used in WIFM

Boundary Conditions

29. The solution matrix for each row and column results in $N-2$ simultaneous equations containing N unknowns. The boundary conditions supply the remaining two unknowns needed to solve the matrix. A variety of boundary conditions are permissible and can be classified into three general groups; (a) open boundaries, (b) land-water boundaries, and (c) subgrid barrier boundaries.

Open boundaries

30. This category includes seaward boundaries terminating at the edge of the computational grid and river channels entering/exiting the two-dimensional grid at any point within the grid. Water levels and/or flow rates at the boundary points are prescribed as functions of location and time. Additional open boundary conditions (for storm surge applications) include specification of the hydrostatic elevation, η_a , computed by the Standard Project Hurricane (SPH) model and a uniform flux boundary condition, where boundary values are estimated from parameters within the grid. Additional research is being conducted to add a radiation condition option at open boundaries.

Land-water boundaries

31. WIFM employs a deterministic approach for simulating flooding and drying of low-lying terrain. As water levels rise during a tidal cycle or storm surge, grid cells that were once dry become flooded and are incorporated into the Navier-Stokes computations.

32. Initially, water is transferred from one cell to an adjacent dry cell based on discharges computed by a broad-crested weir formula:

$$q = C_o d^{3/2} \tag{4-21}$$

where

q = water discharge per unit width

C_o = admittance coefficient

d = average water level difference between the cells

33. The incremental water level increase in the receiving cell is computed by:

$$\eta_r = \frac{\Delta t q}{\Delta x_r} \tag{4-22}$$

where

η_r - incremental water level increase

Δt - time-step

Δx_r - width of the receiving cell

When the receiving cell's water level exceeds a small prescribed value, it is incorporated into the Navier-Stokes computations.

34. To ensure that mass is conserved in the system, an equal volume of water added to the receiving cell must be subtracted from the donating cell. Thus, the incremental decrease in the donating cell's water level is calculated by:

$$\eta_d = \frac{\Delta t q}{\Delta x_d} \tag{4-23}$$

35. The drying algorithm is essentially the inverse of flooding. If a cell's water level recedes below a predetermined level, that cell is removed from the Navier-Stokes computations, and water is then transferred to an adjoining cell with rates determined by the broad-crested weir formula presented above. However, this formula is used only until the water level recedes below a second predetermined level. At that time, water is drained at a rate equal to a fraction of the remaining water volume.

36. Because the flood/dry scheme transfers water from cells residing in the Navier-Stokes computational domain to cells outside this domain, discontinuities or noise is generated in the flow field solution. Noise is also generated when cells are added to, or deleted from, the computational domain. Since affected cells typically have low water levels, resulting in high bottom friction effects, noise is dampened in successive time-step calculations.

37. To provide sufficient time for bottom friction to dampen noise, and prevent excessive noise generation by cells repeatedly entering and exiting the Navier-Stokes calculations, time constraints are imposed on the flood/dry scheme. That is, a dry cell must remain dry for a minimum number of time-steps before flooding can occur. Similarly, a "wet" cell must remain in the computational domain for a minimum number of time-steps before exiting the computational domain. Experience has shown that a time period of 5 min for

storm surge studies and 20 min for tidal studies is sufficient for dampening noise.

Barriers

38. Subgrid barriers refer to flow field obstructions, such as breakwaters, whose widths are much narrower than the widths of adjacent grid cells, but whose lengths are at least as great as the length of a grid cell. Though treated as impermeable, barriers can go through alternating periods of being submerged and exposed during a tidal cycle or storm surge.

39. Barriers are categorized into three types; (a) exposed, (b) submerged, and (c) overtopping. Each barrier is permitted to change categories during a simulation, thus allowing a barrier that is submerged during periods of high water levels to become exposed after the water levels have receded. Exposed barriers impose a no-flow condition where velocities at the barrier are zero. Submerged barriers are included in the Navier-Stokes computations and serve as starting and ending points for computational segments.

40. Barrier overtopping occurs when (a) water levels on one side of the barrier are higher than the barrier, while levels on the opposite side are lower than the barrier, or (b) when water levels on both sides of a barrier are higher than the barrier, but levels are less than a small prescribed level (i.e. the barrier is not quite submerged). For both situations, flow discharges across a barrier are computed by a broad-crested weir formula algorithm similar to the flood/dry scheme.

41. Discharge volumes are subtracted from the cell whose water level is above the barrier. An equal volume is added to the opposite cell, assuring that water volume is conserved in the system. Because these computations occur after the Navier-Stokes computations, small instabilities are generated. Similar to the flood/dry algorithm, time controls are imposed to ensure that bottom friction effects have sufficient time for dampening these instabilities. Thus, an overtopping barrier must remain as an overtopping barrier for a minimum number of time-steps and a submerged barrier must remain as a submerged barrier for a minimum number of time-steps. The number of time-steps is specified by the user and has a default value of five time-steps.

PART III: DEFINITION OF INPUT DATA FORMAT

42. The input data set format was designed to resemble the format required by the series of models released by the USAE Hydrologic Engineering Center. It is the intent that this structure, being familiar to Corps personnel, will reduce the time needed to learn this system. The general format of the input data set records, where a record refers to one line of data, is presented below:

a. Each record is divided into 10 fields containing 8 columns each.

b. Field 1, columns 1 through 8, contains a mnemonic identification label that describes the purpose or function of each record.

c. Fields 2 through 10 contain data that may be real, integer, or character in type. Integers must be right justified. Real numbers must also be right-justified if the decimal point is omitted. Character data do not need to be right- or left-justified.

d. Array data, such as depths, are read with DO or Implied DO loops. No label is required for each record containing array data. However, a general specification record, such as BATHSPEC, which defines bathymetric attributes, must precede that array.

43. Spelling of record identification labels and alphanumeric variables is important. Misspelled entries will result in either recognized error conditions that force the model to abort execution, or bypassing of desired user-defined operations, such as saving time-history data.

44. Certain records and variables have been assigned default values in the model for minimizing input data and computer resources. Thus, not all input data records will be needed for each application, and only those records pertinent to the simulation or required by the model should be included. Default values are representative of those chosen in previous studies performed by CERC. Although these quantities may not be applicable to all studies, they can serve as a guide when selecting replacement values.

45. Default values are processed when the record field corresponding to that variable is blank. Hence, the user must be careful when leaving fields blank in a record; blank fields will not necessarily result in a variable being assigned a value of zero. These variables and their respective default

values are noted in Appendix 4-A. The following discussion pertains to the general format of the input records given in Appendix 4-A.

46. Each record is presented in a standardized tabular format and has as its heading the mnemonic identification label or name with a brief description of its function. Following its name, the record has an abbreviated note documenting whether it is required for a simulation. These abbreviations have the following definitions:

(Req)	Record or variable is required for each simulation.
(Opt)	Record or variable is optional. Omitting this item results in either the default value being used or the defined operation not being performed.
(C-opt)	Record or variable is required if related or parent options have been selected.

For example, record TIMESPEC, presented in Appendix 4-A, contains the note (Req), meaning that this record must reside in the input data set for each simulation. Record CHNGBATH contains the note (Opt) meaning this record is optional and is used only when changes to the bathymetric data are desired. Record XSTRETCH contains the note (C-opt), meaning this record is required only if a stretched Cartesian grid has been specified on the GRIDSPEC record.

47. Input variables, presented in column 2 of each table, are referenced to their respective record fields shown in column 1. Generally, data for each variable occupy a single 8-column data field. However, variables assigned titling or formatting information can occupy several fields.

48. Variable attributes are presented in columns 3 through 6 of each table. Valid data types are listed in column 3 and can be real, integer, or alphanumeric. Abbreviations presented in this column are described below:

Char*16	Alphanumeric character string containing up to 16 characters
Char*8	Alphanumeric character string containing up to 8 characters
Integer	Integer data
Real	Real (floating point) data

49. Column 4 of each table defines whether the respective variable must be assigned a value. Abbreviations listed in this column have identical meanings as those for the records. Default values are listed in column 5. A blank entry in this column denotes that the respective variable is not assigned a default value.

50. Column 6 of each table lists the variables' permitted data type or all valid character strings. Variables having integer or real data types are specified with the following notation:

A	Alphanumeric values
+R	Positive real values
R	Positive, zero, or negative real values
+I	Positive integer values
I	Positive, zero, or negative integer values

51. Variable definitions are listed in table column 7 of each table. Variables whose quantities are unit-dependent contain a reference to that variable designating its system of units. For example, variable TMAX is assigned a value having units defined by variable TUNITS. Variables defining input data units, and on which record they reside, are presented below.

Variable	Record	Definition
BUNITS	BATHSPEC	bathymetry/topography data
FRUNIT	FRICTION	declares bottom friction law
FUNITS	FUNCTION	tidal and discharge boundary data
GUNITS	GRIDSPEC	numerical grid data
PUNITS	WINDSPEC	atmospheric pressure data
SUNITS	GENSPECS	model computations and output
TUNITS	TIMESPEC	time-dependent variables
WUNITS	WINDSPEC	wind velocity data

PART IV: DISCUSSION OF INPUT DATA REQUIREMENTS

52. The types of data processed by WIFM are extensive and encompass a wide range of possible applications. Since each application is unique, the type of input data required for each study will vary. In this discussion of model input, data have been divided into six categories to present model capabilities and data requirements. These categories are:

a. Model control specifications.

b. Grid description.

c. Physical characteristics.

d. Boundary conditions.

e. Wind-field specifications.

f. Output specifications.

53. Table 4-2 presents WIFM input data records pertaining to each category. A record refers to one line of data, and each record begins with a mnemonic character string to identify one record type from another. Record format and detailed specification for each record are contained in Part IV. While reading Part IV, the user will find it beneficial to refer to Appendix 4-A.

Model Control Specifications

54. Model control parameters define how the user wants to control the model's execution. Records contained in this category include GENSPECS, TIMESPEC, STARTUP, and ADDTERMS.

55. Record GENSPECS is used to specify the general title of the simulation (TITLE) and the system of units (SUNITS) used for model computations and displaying model results. Variable names are given in parentheses. In addition to the general title, other input data records have provisions for titles. Although this information is optional, it can be very helpful when reviewing a series of simulations. A title should specifically state data set attributes, such as data source or collection date, to differentiate it from data used in other simulations.

56. Model output is presented in either English or metric units. However, the user can specify a different system of units for the input data.

Table 4-2

Input Data Set Records

Category	Record Name
Model control specifications	GENSPECS TIMESPEC STARTUP ADDTERMS
Grid description	GRIDSPEC XSTRETCH YSTRETCH TURNOFF
Physical characteristics	BATHSPEC CHNGBATH FDRYSPEC FRICTION FRICTABL CHNGFRIC XBARRIER YBARRIER BARRSPEC
Boundary conditions	XBOUNDRY YBOUNDRY FUNCTION CNRECORD CONSTIT TERECORD TFRECORD TABELEV TABFLOW
Wind-field specifications	WINDSPEC SPHSPEC TABSPH TABWINDS
Output specifications	PRWINDOW RECGAGE RECSNAPS XRECRANG YRECRANG

For example, the user can supply wind velocity data having units of either miles per hour, feet per second, meters per second, or knots. WIFM will perform the necessary conversion to place the input data into the system of units used for computations.

57. Record TIMESPEC controls the processing of all time-related variables. Variable DELT defines the time-step or time interval between consecutive flow field computations and has units of seconds. Variable TUNITS controls the units of all other time-dependent variables (e.g., variable DTGAGS). Valid units for TUNITS are hours, minutes, and seconds.

58. For meaningful model results, the selected time-step must be consistent with the Courant criteria, C_r, discussed under model limitations. The maximum permissible time-step size for a given value of C_r can be computed from:

$$C_r = \frac{\sqrt{gh}}{\Delta x / \Delta t} \qquad (4\text{-}24)$$

where

- g - gravitational acceleration
- Δx - dimension of the smallest grid cell within the computational domain
- h - depth at that cell
- Δt - time-step size

Experience indicates that the value for C_r should be less than 5. Larger values of the Courant number may be permissible at a distance from the area of interest within the computational domain; however, numerical accuracy will be affected.

59. Variable TPROV defines the provisional model time at the start of the simulation, and variable TMAX controls the simulation's duration. TMAX must be an integer multiple of the time-step, variable DELT. Typically, a simulation begins at time 0.0 and has a duration ranging from one to several days. This duration provides the hydrodynamic model sufficient time in which to develop accurate tidal circulation fields and avoids the generation of numerical instabilities induced by instantaneously applying forces to a static water basin. Additional details concerning duration are discussed with tidal boundary conditions.

60. Variable DTGAGS specifies the frequency at which numerical gage time-history data (i.e., water velocities and free surface elevations) are

saved for future processing by the post-processing package in the CMS. Quantities assigned to this variable _must_ be an integer multiple of the time-step variable DELT. Numerical gage locations (locations for which time-histories are saved) are selected with the RECGAGES record, which is discussed in the model output specifications section. Variable DTHOTS defines the time interval for saving field data for use in another simulation (see STARTUP record). Quantities assigned to this variable _must_ be an integer multiple of the time-step DELT.

61. The STARTUP record defines the flow field conditions at the start of a simulation. Normally, the flow field is assumed to be static (SELEV=0). Although this assumption may not be entirely correct, it is often necessary because prototype data rarely have the resolution to accurately define the flow field throughout the model domain at the start of a simulation. To dampen computational instabilities associated with static initial conditions, the simulation should begin several hours before the time of interest.

62. Initial conditions can also be supplied from a previous simulation (SELEV = HOTSTART). These simulations must be sequential in time since the second simulation is a continuation of the first. When initial conditions are supplied from a previous simulation, the second simulation is referred to as a "hotstart." Slight computational inaccuracies also exist for hotstart conditions due to data round-off incurred by storing data on a computer disk. These precision errors cause instabilities that are significantly smaller than those generated from starting with static conditions and can be minimized by overlapping the simulations. Overlapping is performed by saving the hotstart data file approximately 10 to 20 time-steps before the end of the first simulation. The second simulation is then run with this hotstart file. When analyzing model results, the user should ignore the repeated (overlapping) time-steps.

63. When a hotstart is selected, variable TPROV on record TIMESPEC must be set to the time when the desired field data were saved. These times are printed in the input data summary file of the preceding run. The hotstart simulation will begin at time TPROV and end at time TMAX + TPROV. Therefore, the user should not incorporate the simulation time of the previous run into variable TMAX. All remaining time variables should reflect the change in starting time. The STARTUP record also contains variable SECHO. A brief or

full report of input data is written to the output file (FNPRNT) by specifying SECHO equal to SHORT or DETAILED, respectively.

64. Record ADDTERMS must reside in the input data set if either the inertial or the diffusion terms are to be computed in the Navier-Stokes calculations. Variable ADVTYP is set to NOADVECT for no inertial terms, NONCONS to include inertial terms in their nonconservative form, or CONSERV to include the inertial terms in their conservative form.

65. An eddy viscosity coefficient must be specified if diffusion is computed. Diffusion is set with variable DIFTYP equal to NODIFFUS for no diffusion, CONSTDIF for diffusion with a constant eddy viscosity coefficient, or VARDIF for diffusion with a variable eddy viscosity coefficient. The value of the eddy viscosity coefficient is defined by variable DIFCOF and can be constant or variable. Rainfall, groundwater flow, and evaporation are accounted for in the system with variable ADMASS on the ADDTERMS record.

Grid Description

66. The study area is defined in the model via a computational grid. The grid is composed of rectilinear cells, where each cell is assigned a two-dimensional index. The first index (i) corresponds to the x-coordinate, and the second index (j) corresponds to the y-coordinate. The grid index system is presented in Figure 4-6. All flow field data, such as depths, are assigned and referenced to their respective grid cells with this system. Guidelines for developing grids are discussed in Appendix A of the *CMS User's Manual*.

67. WIFM permits a rectilinear stretched grid coordinate system, where successive grid cells can smoothly vary in width. Grids with uniform width cells are also permitted. Procedures for constructing a grid are presented in documentation of package CMSGRID (Appendix A of the *CMS User's Manual*). CMSGRID guidelines for grid generation pertaining to hydrodynamic models are therefore useful for WIFM applications.

68. Selection of grid coordinate systems is controlled by variable GRTYPE on record GRIDSPEC. A uniform, or constant grid cell size is selected by assigning the character string RECTANG to variable GRTYPE, whereas string RSTRETCH selects a stretched rectilinear grid. If the stretched grid option is selected, record GRIDSPEC must be followed by a set of XSTRETCH and YSTRETCH records (Table 4-3). These records are generated by the interactive

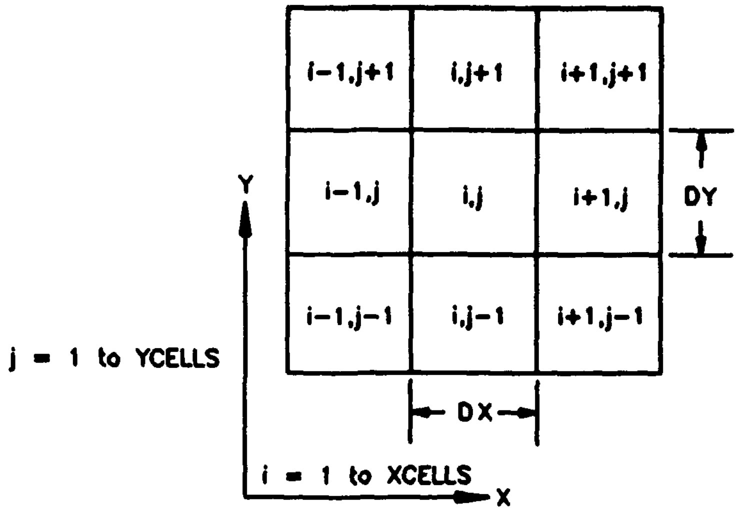


Figure 4-6. Definition of coordinate system and grid cell convention

Table 4-3

Sample XSTRETCH and YSTRETCH Records

XSTRETCH	1	4	-.696333695	.696333695	.933460501
XSTRETCH	4	9	-6.69031772	5.80606023	.277821490
XSTRETCH	9	19	.143110486	.710267924	.770050578
XSTRETCH	19	26	.167892340	.730987967	.809764231
XSTRETCH	26	45	.188997542	.786653891	.897775643
YSTRETCH	1	17	-.500000000	.500000000	1.00000000
YSTRETCH	17	26	.177832310	.755987967	.823454231
YSTRETCH	26	35	.500000000	.500000000	1.00000000
YSTRETCH	35	47	.199875847	.788797546	.887865638
YSTRETCH	47	55	6.89654455	5.77767885	.277896445
YSTRETCH	55	70	.123478445	.556789654	.234564567

grid generation program MAPIT contained in package CMSGRID and can be placed directly into the input data set without modification. The reader can refer to Appendix A of the *CMS User's Manual* for more information on XSTRETCH and YSTRETCH.

69. Variable GUNITS on record GRIDSPEC controls the system of units for the computational grid. Valid units are ENGLISH and METRIC. WIFM will

convert the data to the system of units for computations (SUNITS) internally. Variables XCELLS and YCELLS specify the number of grid cells in the x- and y-directions, respectively. Variables DX and DY on record GRIDSPEC specify a grid's spatial mapping scale in the x- and y-directions, respectively. For uniform grids that were not generated by program MAPIT, these variables are assigned the physical width of a single cell. For stretched rectilinear grids, variables DX and DY are assigned the value 1.0 if physical distances were used in generating the grid. The variables DX and DY are assigned the value of the map scale if relative map distances were used in generating the grid. For example, a map with a scale of 1:80,000 is used to generate a stretched rectangular grid. If the physical map distances (i.e., distances computed using the appropriate scaling) are used to generate the mapping coefficients, then DX and DY are 1.0 because no conversion is necessary. However, if the map distances (i.e. grid distances measured in map inches) are used to generate the mapping coefficients, then DX and DY must be 6666.67 to convert map inches to physical distances (in feet).

70. Variables GLATT and GLONG specify the latitude and longitude of the grid origin in decimal degrees, respectively. GALIGN specifies the counter-clockwise rotation of the x-axis from due east (in decimal degrees).

71. Because of manpower costs associated with development of a computational grid, a user should construct a grid with conservative limits in the lateral and longshore directions. Grid dimensions can then be minimized with record TURNOFF. This record permits a user to remove entire rows or columns of cells from the Navier-Stokes and/or flood-dry calculations along a grid boundary without generating a new grid. When boundary cells are removed, boundary conditions must be moved accordingly. Variables (OFFX1,OFFY1) and (OFFX2,OFFY2) define the "patch" of cells to be removed from computations. Variables OFFX1 and OFFX2 on the TURNOFF record specify the minimum and maximum cell numbers in the x-direction, respectively, where cells will be removed from the computations. Similarly, variables OFFY1 and OFFY2 on the TURNOFF record specify the minimum and maximum cell numbers in the y-direction, respectively, where cells will be removed from the computations. More than one TURNOFF record is permitted.

72. When this record is applied to cells within the grid interior, the model will treat these cells as land that will never flood. A zero flux

boundary condition is imposed at the faces of removed cells. Though cells are removed using this record, the grid cell numbering scheme is not affected.

Physical Characteristics

73. A study area's physical characteristics include its (a) topography/bathymetry values, (b) bottom friction coefficients, (c) flooding and drying parameters, and if applicable, (d) any barriers or obstructions influencing tidal circulation or storm surge levels. Records pertaining to each of the above topics are described individually in the following sections.

Topography/bathymetry

74. Each grid cell must be assigned a water depth or land elevation. Topography/bathymetry data are referenced relative to an arbitrary datum. Typically, the map datum from which the depths are taken is used. Water cells are designated by negative values, whereas land cells have positive values.

75. One BATHSPEC record is required for defining the general characteristics of the topography/bathymetry array and must precede this array. Variable BUNITS defines the units of topography/bathymetry data. Valid units are feet, meters, or fathoms. The input sequence for reading this array is controlled by variable BSEQ. Eight options for the input sequence are available for reading the array data and are documented in Table 4-4. As an example, for the first input sequence (Figure 4-7), the depths are read along the x-direction; then y is incremented to a value of 2, and again the sweep in the x-direction takes place. This procedure is repeated until the entire array is read. The input format for reading this array can be selected by the user with variable BFORM.

76. The maximum water depth is specified with variable DLIMIT, and any array values deeper than DLIMIT are set to DLIMIT (in BUNITS). Grid-wide adjustments to land elevations contained in the topography/bathymetry array can be made with variable LDATUM. The value assigned to this variable is added to all land cells in the grid. Positive LDATUM values will increase land elevations, whereas negative values will decrease land elevations. Similarly, grid-wide adjustments to water depths can be made with variable WDATUM. The value assigned to this variable is added to all water cells. Since these cells have negative values, positive WDATUM values produce shallower basins.

Table 4-4

Input Sequence for Array Data

No	Sequence	Description
1	XY	`DO 1 J=1,YCELLS` `1 READ(LUN,FORM) (VAR(I,J),I=1,XCELLS)`
2	-XY	`DO 2 J=1,YCELLS` `2 READ(LUN,FORM) (VAR(I,J),I=XCELLS,1,-1)`
3	X-Y	`DO 3 J=YCELLS,1,-1` `3 READ(LUN,FORM) (VAR(I,J),I=1,XCELLS)`
4	-X-Y	`DO 4 J=YCELLS,1,-1` `4 READ(LUN,FORM) (VAR(I,J),I=XCELLS,1,-1)`
5	YX	`DO 5 I=1,XCELLS` `5 READ(LUN,FORM) (VAR(I,J),J=1,YCELLS)`
6	-YX	`DO 6 I=1,XCELLS` `6 READ(LUN,FORM) (VAR(I,J),J=YCELLS,1,-1)`
7	Y-X	`DO 7 I=XCELLS,1,-1` `7 READ(LUN,FORM) (VAR(I,J),J=1,YCELLS)`
8	-Y-X	`DO 8 I=XCELLS,1,-1` `8 READ(LUN,FORM) (VAR(I,J),J=YCELLS,1,-1)`

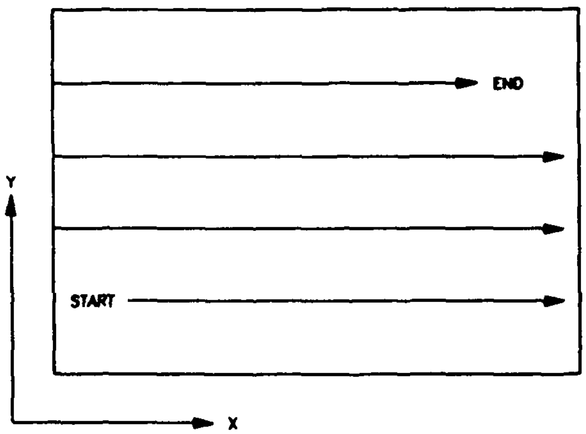


Figure 4-7. Input sequence - option 1

77. Changes to the topography/bathymetry array can also be made to individual cells or to a group of cells with record CHNGBATH. This record allows the user to quickly change values assigned to the bathymetry array (using variable BATH) without editing the array itself. It should be noted that (a) values of the variable BATH on the CHNGBATH record are assumed to have units consistent with those selected for bathymetry/topography (i.e., variable BUNITS on record BATHSPEC), and (b) LDATUM and WDATUM are not applied to cells specified with record CHNGBATH; therefore, the effect of nonzero LDATUM and WDATUM must be included in the value of variable BATH.

78. Variables X1INDX and X2INDX on the CHNGBATH record specify the minimum and maximum cell numbers in the x-direction, respectively, where the bathymetry/topography value will change. Similarly, variables Y1INDX and Y2INDX on the CHNGBATH record specify the minimum and maximum cell numbers in the y-direction, respectively, where the bathymetry/topography value will change. More than one CHNGBATH record is permitted.

Flooding and drying

79. Flood/dry calculations are made only at those cells whose elevations/depths are within the limits defined by variables ALLDRY and ALLWET on the FDRYSPEC record (Figure 4-8). Cells having elevations greater than ALLDRY remain as dry land and are not checked for flooding, whereas cells whose depths are deeper than ALLWET remain as water cells and are not checked for drying.

80. Variables ALLDRY and ALLWET are assigned conservative default values of 30.0 and -20.0 ft, respectively. Because cells are checked for flooding and drying every time-step, a narrower range of values reduces the number of cells to be checked and can significantly reduce the execution time of a simulation. However, default values should not be changed arbitrarily. If variable ALLDRY is set too low, cells that would ordinarily flood during the course of rising water levels are prevented from doing so. This results in underestimating the extent of inundation within the study area and overestimating water levels in "wet" cells adjacent to the shoreline. Similarly, if variable ALLWET is too high, cells which should be dry are forced to remain in the Navier-Stokes computations causing the model to go unstable or produce results that are meaningless (and often go undetected). This possibility is extremely dangerous because all subsequent Navier-Stokes computations will be affected.

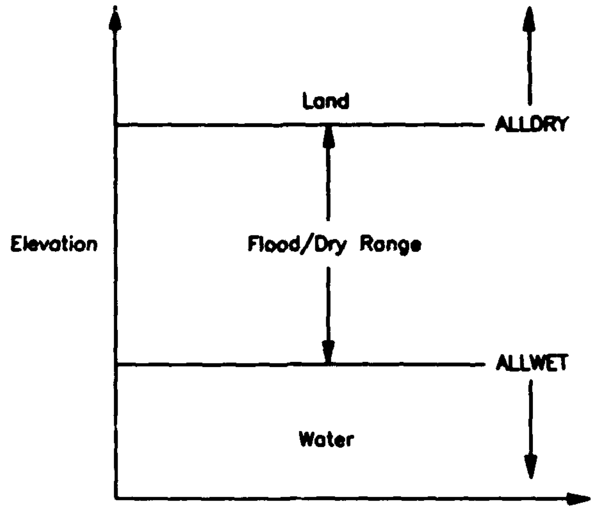


Figure 4-8. Limits of the flooding
and drying range

81. Determining new limits can be made by performing a series of "worst case" simulations. In these simulations, conservative flood/dry limits are chosen, and the model is run with those storms or events that will produce the highest flood and the lowest dry elevations. The maximum and minimum water levels experienced at each cell are printed in the input data summary. These values are measured relative to each cell's bottom and should be added to the depth array for determining appropriate limits.

82. Several criteria must be met before a dry cell can be included in the Navier-Stokes computations:

a. A cell's water level, measured relative to its bottom, must exceed a prescribed minimum values.

b. A cell must be dry for a predetermined length of time, and that time must exceed one time-step.

Variable CEPSD on record FDRYSPEC defines the minimum water level needed for inclusion of dry cells into the Navier-Stokes computations. Acceptable values based on experience range from 0.2 to 0.5 ft, measured relative to the bottom of the cell.

83. A cell is removed from the Navier-stokes computations if its water level falls below one-half of variable CEPSD's quantity and if it has remained in the Navier-Stokes calculations for at least the period of time defined by

variable TIMOPN. This variable is generally assigned a value of 5 min for storm surge and 20 min for tidal circulation studies. Similarly, variable TIMCLS specifies the minimum time period required for a cell to remain dry before it can be included in the Navier-Stokes computations. This variable is generally assigned a value of 5 min for storm surge applications and 20 min for tidal circulation studies.

84. Variable CFWEIR is a weir coefficient for cell flooding and drying. The value of CFWEIR is used for the admittance (or weir) coefficient, C_o , in Equation 4-21 and has a default value of 4.0.

85. Variable CDRAIN is a recession coefficient specifying the volumetric rate at which water is drained from one cell to an adjacent cell. This value is expressed as a fraction of the total water volume contained in the cell. For example, a value of 0.10 results in 10 percent of the water volume contained in a cell being drained after each time-step. Typical values assigned to variable CDRAIN range from 0.10 to 0.20. The default value for CDRAIN is 0.1. Values greater than 0.20 may result in numerical instabilities if the transferred water volume appreciably raises the receiving cell's water level. Therefore, values greater than 0.20 should not be used.

Bottom friction coefficient

86. Several choices are available for specifying bottom friction parameters. First, parameters may be expressed with either a Chezy friction loss coefficient or a Manning's friction factor. This designation is made with variable FRUNIT on record FRICTION. The model, which uses the Chezy friction loss coefficient in the bottom friction calculations, converts Manning's n friction factors into Chezy's C_z coefficients by the following relationship:

$$C_z = \frac{d^{1/6}}{n} \tag{4-33}$$

where

C_z = Chezy friction loss coefficient

d = total water depth

n = Manning's friction factor

Quadratic friction is the only option presently available in WIFM and is specified by setting FRLAW to QUADRAT on record FRICTION.

87. Bottom friction coefficients may be specified as constant values (FRDEF = CONSTANT) or as functions of depth/elevation (FRDEF = VARYBATH). For the constant value option, separate friction coefficients can be assigned to land and water cells. Friction coefficients for land are assigned to variable FRLAND, and coefficients for water cells are specified by variable FRWATR. A coefficient is assigned to each cell based on its topography/bathymetry value at the start of a simulation and will remain constant throughout the simulation, regardless of flooding/drying effects.

88. The depth-variable friction option requires a least two FRICTABL records, which must follow immediately after the FRICTION record in the input data set. Each FRICTABL record must contain a depth/elevation (FDEPTH) and a corresponding friction value (FRICT) for creating a tabular friction function. Cells with a water depth less than or equal to FDEPTH are assigned a friction value of FRICT. Cells whose depths are deeper than the minimum depth entered in the table are assigned the friction coefficient corresponding to the minimum table depth.

89. In deep water, bottom friction has a negligible effect on long-wave hydrodynamics. Variable FDMAX on record FRICTION defines the maximum depth where bottom friction influences the hydrodynamics. It is provided for reducing computer memory requirements when the depth-variable option is requested and has a default value of -300.0 ft.

90. Friction coefficients can also be assigned to individual cells or a group of cells with record CHNGFRIC. Record CHNGFRIC overrides the above options for all cells entered on this record. This permits the user to change a cell's friction coefficient in certain areas, such as rivers, where parameters differ from the norm. Friction coefficients (FRICT) defined on this record must be consistent with the bottom friction law selected (i.e., Chezy or Manning coefficient) selected by variable FRUNIT on record FRICTION. Variables (X1INDX, Y1INDX) and (X2INDX, Y2INDX) define the "patch" of cells where friction values are to be changed. More than one CHNGFRIC can be used in a simulation. These records must follow FRICTION and, if applicable, FRICTABL records.

Barriers

91. Subgrid barriers refer to flow field obstructions, such as breakwaters, whose widths are much narrower than the widths of adjacent grid cells, but have lengths that are equal to or greater than those of a grid cell.

Though treated as impermeable, barriers can go through alternating periods of being submerged and exposed during a tidal cycle or storm surge.

92. Records pertaining to subgrid barriers include XBARRIER, YBARRIER, and BARRSPEC. Similar to the flood/dry parameters discussed previously, many of the parameters governing overtopping rates have been determined through modeling experience. Default values are provided for these terms, and it is recommended that the user not change these values unless there is just cause for doing so. Discharge rates across a barrier can be stored with either records XRECRANG or YRECRANG and are discussed under model output capabilities.

93. Barriers that prevent or impede flow in the x-direction (i.e., perpendicular to the x-axis) are specified with XBARRIER records (Figure 4-9). A barrier for a particular cell is defined at the cell face, where the velocity is also defined. Barrier grid locations are defined with variables BRPOS1, BRPOS2, and BRPOS3. Variable BRPOS1 is assigned the barrier's grid cell X-index, and variables BRPOS2 and BRPOS3 are assigned the barrier's starting and ending grid cell Y-indices, respectively.

94. Similarly, YBARRIER records define those barriers that prevent or impede flows in the y-direction. Variable BRPOS1 is assigned the barrier's grid cell Y-index. Variables BRPOS2 and BRPOS3 are assigned the barrier's starting and ending grid cell X-indices.

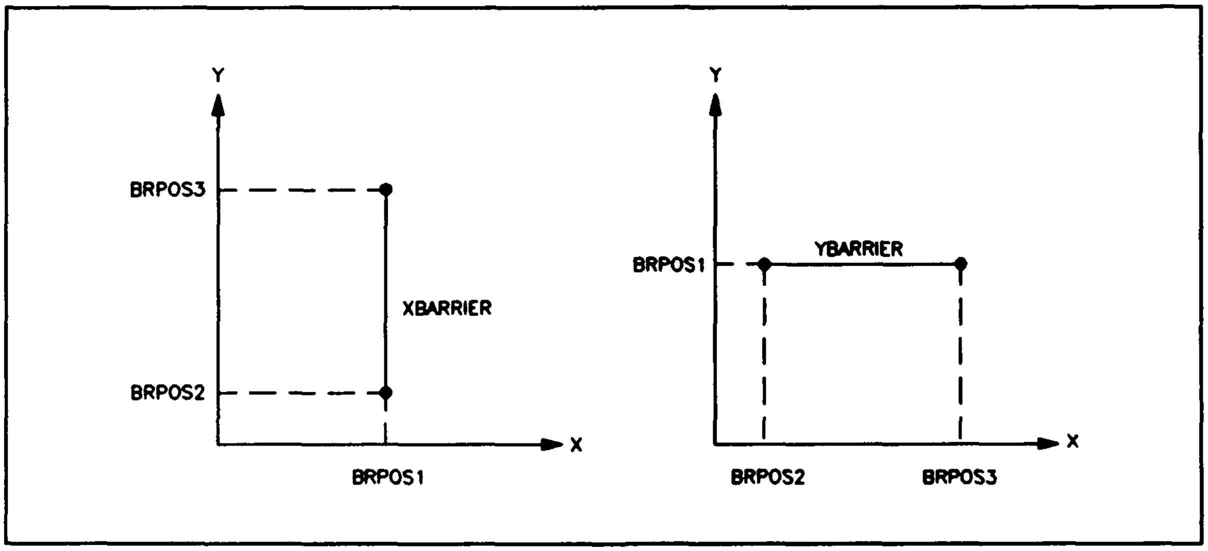


Figure 4-9. Definition of XBARRIER and YBARRIER

95. A barrier's crest elevation, assigned to variable BARHT, is measured from the water-level datum to the barrier's crest. For example, a barrier crest of 2.0 ft means that the top of the barrier is 2.0 ft above the datum. Conversely, a value of -2.0 ft sets the crest at 2.0 ft below the datum. These values need not be modified for hotstart simulations.

96. Barriers are categorized into three types: exposed, submerged, and overtopping. Each barrier is permitted to change categories during a simulation, allowing a barrier that is submerged during periods of high water to become exposed after the water level has receded. Exposed barriers impose a no-flow condition where velocities at the barrier equal zero. Submerged barriers are included in the Navier-Stokes computations.

97. Barrier overtopping occurs when (a) water levels on one side of the barrier are higher than the barrier, while levels on the opposite side are lower than the barrier, or (b) when water levels on both sides of a barrier are higher than the barrier, but levels are less than a small prescribed level (not yet considered submerged). For both situations, flow discharges across a barrier are computed with a broad-crested weir formula algorithm similar to the flood/dry scheme.

98. Discharge volumes are subtracted from that cell whose water level is above the barrier. An equal volume is added to the opposite cell, assuring that water volume is conserved in the system. Because these computations occur after the Navier-Stokes computations, small instabilities are generated. Thus, time controls are imposed to ensure that bottom friction effects have sufficient time for dampening these instabilities.

99. Crests of submerged barriers are assigned a Manning's n friction coefficient with variable BARMAN on record XBARRIER or YBARRIER. This coefficient is independent of those options and quantities assigned to grid cells with records FRICTION, FRICTABL, and CHNGFRIC. The default value for variable BARMAN is 0.025. Because surfaces of man-made barriers tend to be rough in comparison with the surrounding area, this variable may need to be assigned a higher friction coefficient.

100. Variable BARCOF, similar to variable CFWEIR in the flood-dry algorithm, is the admittance or weir coefficient in the broad-crested weir formula. This variable is initialized to a default value of 2.7 (English) or 4.9 (metric). Barriers can be identified by assigning each one a barrier name with variable BARNAM on the XBARRIER or YBARRIER records.

101. Overtopping control parameters (variables BEPSD, TIMSUB, and TIMOVT) are specified on record BARRSPEC and are applicable to each barrier. (The BARRSPEC record should follow all XBARRIER and YBARRIER records.) Variable BEPSD prescribes the water surface level, measured relative to a barrier's crest, to initiate/terminate overtopping computations. Once water levels in both adjacent cells exceed this value, the barrier will be treated as submerged. Similarly, if the water level of one cell falls below this value, a submerged barrier will then be treated as an overtopping barrier.

102. Due to stability considerations discussed previously, a barrier is not permitted to change categories every time-step. The minimum time period before a submerged barrier can become an overtopping barrier, and vice versa, is controlled by variable TIMSUB. Similarly, variable TIMOVT specifies the minimum time period required before an overtopping barrier can become an exposed barrier (and vice versa). Typical times assigned to these variables are 5 min for storm surge applications and 20 min for tidal circulation studies. A generalized default value of 5 times the time-step is built into the model.

Boundary Conditions

103. WIFM is generally applied in regions where at least one grid boundary lies in open water. For example, in open coast regions, the seaward boundary may be located at the continental shelf. In these cases, the flow field is typically driven or forced by prescribing a time-series of water surface levels along this boundary throughout a simulation. Regions may also contain a river whose flow influences local circulation patterns. These river flow rates can be specified as a function of time. Other forcing functions can include, for storm surges induced by hurricanes, the atmospheric pressure anomaly.

104. To encompass as many modeling scenarios as possible, four types of open boundary conditions are incorporated into this model, including:

- a. Tidal elevation.
- b. Discharge.
- c. Inverted barometer.
- d. Uniform flux conditions.

Discussion of these open boundary conditions is presented in three parts. First, an overview of each type of open boundary is given which describes its application and attributes. Second, input data requirements for defining a boundary's grid location are presented. Third, input data requirements for entering time-series data are described.

Overview of open boundary conditions

105. With the tidal elevation boundary condition, the flow field is driven by specifying the water surface elevations as a function of space and time along a grid's outer boundary. Water surface elevations are measured relative to the topography/bathymetry datum and can be supplied from tidal constituent parameters or tabulated data.

106. Two options are available for specifying the spatial distribution of data along a boundary. The first option applies a spatially constant elevation function across a boundary segment where each cell in the segment acts in unison, having identical water surface elevations at each time-step. This option is normally applied along a grid's lateral boundary (i.e., perpendicular to the shoreline) in areas of deep water. It can also be used along a seaward boundary if no significant phase or elevation differences occur along this segment.

107. The second option is a spatially variable elevation forcing boundary where separate time-series functions are specified at each end of a boundary segment. Elevations for each cell within the boundary are obtained by linearly interpolating the two forcing functions (at each time-step). This option is typically applied along the grid's seaward boundary. A boundary can be treated as one continuous segment or as several segments.

108. With the inverted barometer boundary condition, the flow field is driven with the atmospheric pressure anomaly. For example, as the barometric pressure in a study area decreases, an increase in water level occurs as water is drawn into the area from outlying seas. Conversely, an increase in barometric pressure forces water out of the study area, resulting in lower water levels. Because circulation induced by barometric pressure differences during calm weather are small compared with other forcing mechanisms such as a tide, its use has been limited to storm surge applications performed in conjunction with model SPH.

109. For simulations where a tidal signal is specified at a boundary and hurricane wind fields are computed with model SPH, model WIFM will add the

tidal elevation to the atmospheric pressure anomaly to simulate the combined effects. However, this procedure is valid only in areas of deep water. In this situation, the boundary should be specified as a tidal boundary condition. Model WIFM will internally determine whether to combine the two effects.

110. Discharge boundary conditions can be specified at any interior grid cell face. An error message will be printed and execution terminated if this boundary condition is specified at the edge of the computational grid. Furthermore, depths on each side of the boundary cell faces must be less than zero, signifying water cells. Discharges are required to have units of flow per unit width (i.e., cubic feet/second/foot or cubic meters/second/meter), and flow trajectories are referenced relative to the grid axes. Positive discharge rates define flows directed in the positive x- or y-directions, whereas negative discharge rates define flows directed in the negative x- or y-direction.

111. A uniform flux boundary condition is similar to a river discharge boundary condition in that a flux is applied at the boundary cell face. However, the flux through the cell face is computed internally by the model, as opposed to a user-defined flux. This boundary condition assumes that the flux through the boundary cell face equals the flux through the opposing cell face.

112. Since the uniform flux boundary condition does not drive a flow field, its application is limited. However, there are two situations where it can be applied. First, it can be applied across the lateral boundaries near the shoreline (Figure 4-10). Tidal signals generated from constituents, which are normally prescribed as a forcing function along the seaward boundary, should not be used in this reach because bottom friction effects attenuate the tidal signal. Hence, forcing a tidal signal in this reach may not accurately depict the physical processes occurring within the study area.

113. Second, the uniform flux boundary condition may be applicable to steady-state, storm surge analyses of lakes. However, wind must be the only driving force causing surge, and resulting seiches cannot be simulated with this boundary condition.

114. Because the uniform flux boundary condition provides an estimate of the actual flow entering/exiting the grid, its use will introduce error into the flow field solution. Bottom friction effects can dampen these

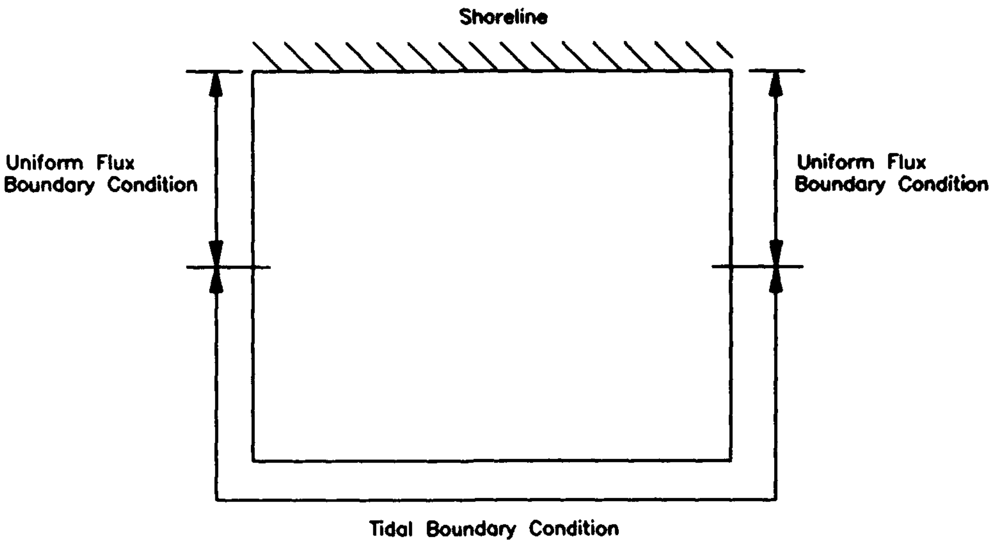


Figure 4-10. Uniform flux boundary condition

inaccuracies, ensuring accuracy of results in the area of interest, if the uniform flux boundaries are placed a suitable distance away from the area of interest. Generally, this distance ranges from 1.5 to 2.0 times that distance measured from the shoreline to the seaward boundary (if it is located at the continental shelf). However, it is suggested that the user perform a series of sensitivity tests to determine whether this estimate is valid for their application (Butler 1982).

115. In the first sensitivity test simulation, the model should be executed with the boundary conditions specified along the grid boundary. Time-series data should be stored at several grid locations that envelop the area of interest. A second simulation should then be performed with the boundary specified several rows or columns inward from the outer grid boundary. All cells outside the "new" grid boundary must be removed from the Navier-Stokes and flood-dry computations (refer to record TURNOFF). Time-series data should again be stored at the same grid locations.

116. Water velocity data saved from these simulations should then be compared. Should differences between data at any gage consistently exceed a small prescribed value, then the outer boundary is too close to the area of interest to use the uniform flux boundary condition. Thus, the user must develop another grid. If, however, velocity differences are within the given

range, additional simulations can be performed to reduce computer costs by eliminating unneeded rows and/or columns along the grid boundary.

Spatial description of open boundaries

117. Each distinct open boundary must be declared by either an XBOUNDRY or a YBOUNDRY record. Record XBOUNDRY defines a boundary that induces or forces flow in the x-direction (i.e., boundary is perpendicular to the x-axis) (Figure 4-11). Conversely, a YBOUNDRY record defines a boundary whose forcing acts in the y-direction.

118. Boundary types are declared on records XBOUNDRY and YBOUNDRY with variable BNDTYP and can be assigned any of the five options previously discussed: (a) spatially constant tide boundaries are selected with character string CONSTELV, (b) spatially variable tide boundaries are chosen with string INTRPELV, (c) spatially constant discharge boundaries are selected with string CONSTDIS, (d) inverted barometer boundaries are chosen with string BAROMETR, and (e) uniform flux boundaries are selected with string UNIFLUX.

119. This model employs a staggered grid cell system where water surface levels, x-direction velocities, and y-direction velocities are defined at different locations on a cell. These positions were defined in Figure 4-4. Elevation and inverted boundary positions are referenced relative to a cell's center and river discharge and uniform flux boundaries are specified along cell faces.

120. Boundary grid positions are defined with variables BNPOS1, BNPOS2, and BNPOS3. For XBOUNDRY records, variable BNPOS1 is assigned the boundary's X-index, whereas variables BNPOS2 and BNPOS3 are assigned the Y-indices of the starting and ending cells, respectively (Figure 4-11). For YBOUNDRY records, variable BRPOS1 is assigned the boundary's Y-index, and variables BRPOS2 and BRPOS3 are assigned the X-indices of the starting and ending cells, respectively. Boundaries can be identified by assigning each one a boundary name with variable BNDNAM on the XBOUNDRY or YBOUNDRY records.

Time-series description of open boundaries

121. Time-series data are required for driving the flow field for three of the boundary options: spatially constant elevation, spatially variable elevation, and spatially constant discharge boundary options. XBOUNDRY and YBOUNDRY variable BNDFN1 (for all three options) and BNDFN2 (for spatially variable elevation boundaries only) define which group of time-series data is to be used to drive the boundary and correspond to the function index number

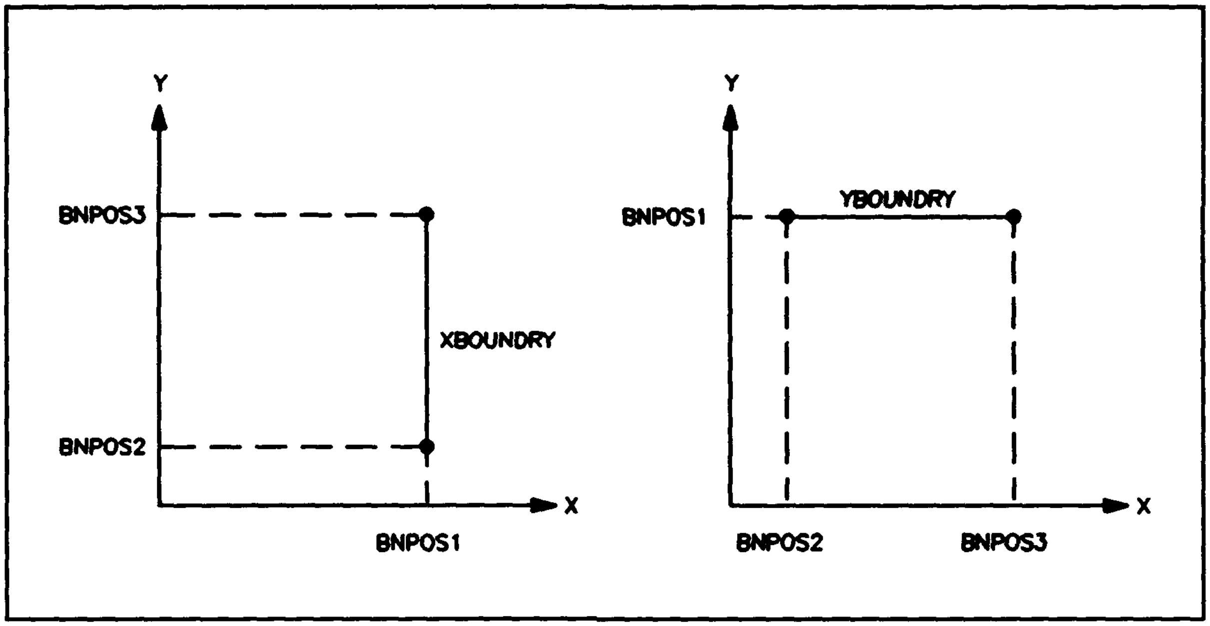


Figure 4-11. Definition of XBOUNDRY and YBOUNDRY

assigned to variable FUNNO on record FUNCTION. For example, an application may have a spatially variable elevation boundary and two spatially constant elevation boundaries (Figure 4-12). This application would require two FUNCTION records (one at each end of the spatially variable boundary) to define the time series at two locations. These values are also used along the spatially constant boundaries.

122. The FUNCTION record is required for time-series data and defines the character of the forcing function driving the boundary. Variable FUNTYP on record FUNCTION is used to determine if the boundary is forced with harmonic constituents (HARMCNST), tabular elevation data (TABELEVS), or tabular discharge data (TABFLOWS). Variable FUNITS defines the units used for the given elevations or flows. The forcing function can be adjusted by shifting it in time (phase shift) or in the vertical (datum shift), or by multiplying the entire time-series by an adjustment factor. Variables FSHIFT, FDATUM, and FMULT on record FUNCTION, respectively, are used to perform these tasks. The forcing function can be gradually spline-fit from initial conditions (usually zero) to the given function value over the time period FEATHR defined on record FUNCTION.

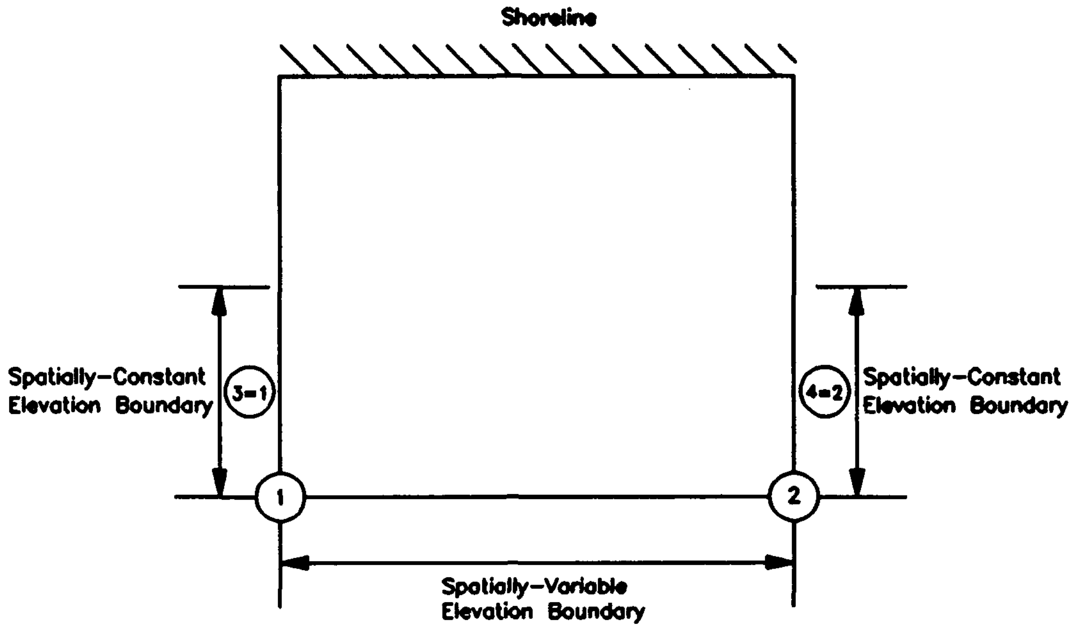


Figure 4-12. Example showing use of BNDFN1, BNDFN2, and FUNNO variables

Harmonic constituents

123. A boundary driven with harmonic constituents (FUNTYP = HARMCNST) requires at least two records to follow the FUNCTION record: one CNRECORD record and at least one CONSTIT record. First, the CNRECORD record specifies the physical coordinates and timing associated with a constituent forcing function. The calendar date (variables RYEAR, RMONTH, and RDAY), time at the start of the simulation (variable RHOUR), and the west longitude of the grid cell where the forcing function is applied (RLONG) are specified on record CNRECORD. Dates and times can be referenced to Greenwich Mean Time (GMT) or local time. GMT is assumed if the longitude (RLONG) equals zero, and nonzero longitude values signal a local time specification. CNRECORD also contains variable RNAME for specifying a record name for the forcing function.

124. One CONSTIT record is needed for each constituent used in generating the time-series data. Variable CNAME on record CONSTIT defines which constituents are selected. Table 4-5 provides a list of the 37 constituents available. A maximum of 37 constituents can be selected (requiring 37 CONSTIT records) and are referenced with the naming convention developed by the National Ocean Survey (NOS). Variable CNAME on record CONSTIT is used to

select any of the constituents listed in Table 4-5. Other data entered on this record include the constituents amplitude (CAMP) and epoch (CEPOCH).

Tabular elevation time series

125. Tabular elevation data can be used to specify, or force, a boundary. WIFM can access components of program TIDEGEN in package CMSUTIL (Appendix B of the *CMS User's Manual*) to internally compute the tabular elevation time-history data from tidal constituents. Each tabular tide boundary requires a TERECORD to precede the actually water surface elevation data. The elevation data can be given at even (constant) time increments (RRINT = real number) or at user-specified (irregular) times (RRINT = IRREGINT).

126. Constant time interval data are entered as a one-dimensional array immediately following record TERECORD. The time interval between entries is specified with variable RRINT (in TUNITS) on record TERECORD. The total number of tabular elevation data entries in the one-dimensional array is specified with variable RENT. The user must also specify which of the array elements corresponds to the start of the simulation with variable RSTART. Typically, this is the first value in the array. However, this variable must be updated for hotstart simulations. Variable RFORM is used to specify the format for reading the one-dimensional array, and variable RNAME is used for naming the tabular tide record.

127. For the irregularly spaced (in time) tabular tide data, a TERECORD and a series of TABELEV records are required. Variable RRINT on record TERECORD is set to IRREGINT for irregularly spaced (in time) tide data. The remaining variables on this record are ignored with this option.

128. One TABELEV record is needed for each tabular tide entry. The elevation (FMAG in FUNITS) and time of occurrence (FHR, FMIN, FSEC in hours, minutes and seconds) are required on each TABELEV record. Elevations are linearly interpolated at those time-steps occurring between entries; therefore, at least two TABELEV records are required. The first TABELEV record must specify the elevation at or before the start of the simulation, whereas the last TABELEV record must specify the elevation at or after the end of the simulation.

Tabular river discharge time series

129. River discharge boundary conditions can be specified at any interior grid cell face. An error message will be printed and execution

Table 4-5

List of Available Constituents

NOS Name	Description
M2	Semidiurnal
S2	Semidiurnal
N2	Semidiurnal
K1	Diurnal
M4	Shallow-water quarter diurnal
O1	Diurnal
M6	Shallow-water sixth diurnal
MK3	Shallow-water terdiurnal
S4	Shallow-water quarter diurnal
MN4	Shallow-water quarter diurnal
NU2	Semidiurnal
S6	Shallow-water sixth diurnal
MU2	Semidiurnal
2N2	Semidiurnal
OO1	Diurnal
LAMBDA2	Semidiurnal
S1	Diurnal
M1	Diurnal
J1	Diurnal
MM	Long period
SSA	Long period
SA	Long period
MSF	Long period
MS	Long period
RHO1	Diurnal
Q1	Diurnal
T2	Semidiurnal
R2	Semidiurnal
2Q1	Diurnal
P1	Diurnal
2SM2	Shallow-water semidiurnal
M3	Terdiurnal
L2	Semidiurnal
2MK3	Shallow-water terdiurnal
K2	Semidiurnal
M8	Shallow-water eighth diurnal
MS4	Shallow-water quarter diurnal

terminated if this boundary condition is specified at an outer-boundary face. Furthermore, depths on opposite sides of the river boundary cell face must be less than zero, signifying a water cell. Discharges are required to have units of flow per unit width (i.e.,cubic feet/second/foot or cubic meters/second/meter).

130. Each river discharge boundary function requires one TFRECORD (analogous to the tabular tide function discussed previously) to precede the flow data. The flow data can be given at even (constant) time increments (RRINT = real number) or at user-specified (irregular) times (RRINT = IRREGINT).

131. Constant time interval data are entered as a one-dimensional array immediately following record TFRECORD. The time interval between entries is specified with variable RRINT (in TUNITS) on record TFRECORD. The total number of tabular flow data entries in the one-dimensional array is specified with variable RENT. The user must also specify which of the array elements corresponds to the start of the simulation with variable RSTART. Typically, this is the first value in the array. However, this variable must be updated for hotstart simulations. Variable RFORM is used to specify the format for reading the one-dimensional array, and variable RNAME is used for naming the tabular flow record.

132. For the irregularly spaced (in time) tabular flow data, a TFRECORD and a series of TABFLOW records are required. Variable RRINT on record TFRECORD is set to IRREGINT for irregularly spaced (in time) flow data. The remaining variables on this record are ignored with this option.

133. One TABFLOW record is needed for each tabular flow entry. The flow rate (FMAG in FUNITS) and time of occurrence (FHR, FMIN, FSEC in hours, minutes, and seconds) are required on each TABFLOW record. Flow rates are linearly interpolated at those time-steps occurring between entries; therefore, at least two TABFLOW records are required. The first TABFLOW record must specify the flow rate at or before the start of the simulation, whereas the last TABFLOW record must specify the flow rate at or after the end of the simulation.

Inverted barometer boundary condition

134. The inverted barometer boundary condition can be selected only if model SPH (Chapter 3) subprogram is used to generate hurricane wind velocity and atmospheric pressure fields in the model. With the inverted barometer boundary condition, water surface elevations are computed from the barometric pressure anomaly. As the barometric pressure decreases, an increase in water surface level occurs. Conversely, an increase in barometric pressure forces the water surface level to decrease.

135. In simulations where a tidal signal is specified at a boundary and hurricane wind fields are used, WIFM will add the effects. This procedure is valid only in deep water. A uniform flux boundary condition (UFBC) should be applied in the nearshore reach of adjacent boundaries. The user should not include an XBOUNDRY or YBOUNDRY record for an inverted barometric boundary condition in the above case.

Uniform flux boundary condition

136. The uniform flux boundary condition UFBC is similar to a river discharge boundary condition in that a flux is applied at the boundary cell face. However, the flux through the cell face is computed internally by the computer as opposed to specifying the flux for a river boundary. This boundary condition assumes that the flux through the boundary cell is equal to the flux through the opposing cell face.

137. Since the uniform flux boundary condition does not drive a flow field, its application is limited. Therefore, care must be taken in applying a UFBC. Selecting an inappropriate reach (length) of the boundary may lead to erroneous results. The user should test the sensitivity of choice by trying other segment lengths which band the chosen reach.

Wind-Field Specifications

138. WIFM can simulate hydrodynamics influenced by either hurricane or uniform (spatially constant) wind fields. However, wind-field calculations are performed only if record WINDSPEC and related records reside in the input data deck. Hurricane wind fields are computed internally in WIFM using components of the SPH wind-field model. Thus, the user need not run model SPH to create wind-field data files for subsequent processing by WIFM.

139. In addition to record WINDSPEC, records required for generating hurricane wind fields include SPHSPEC and TABSPH. These records contain the following information for mathematically describing a hurricane:

a. Peripheral atmospheric pressure.

b. Central pressure index.

c. Track angle.

d. Radius to maximum winds.

e. Maximum wind speed.

f. Angle to maximum winds.

g. Wind inflow angle.

h. Latitude and longitude of storm's eye.

i. Forward speed of storm.

The user is referred to the SPH User's Manual (Chapter 3) for a discussion of input data requirements for records SPHSPEC and TABSPH and guidance for selecting hurricane parameters. Hurricane wind-field input data requirements are identical for WIFM and SPH.

140. Uniform winds are selected by assigning character string TABULAR to variable WTYPE on record WINDSPEC. Winds may be steady (constant) or variable in time. This designation is made with variable WNTRVL set to CONSTANT or VARIABLE, respectively. Steady winds require one TABWINDS record, whereas time-variable winds require at least two records.

141. For the time-variable uniform wind option, one TABWINDS record is typically entered for each hour of the simulation. (More frequent data occassionally exists.) The model will then linearly interpolate to obtain wind speed and direction values at the time interval specified by WINTRP on record WINDSPEC. It should be noted that WINTRP must be assigned a value that is an integer multiple of the time-step DELT.

142. Variable WUNITS declares the system of units for wind magnitudes. Valid units are (a) miles/hour selected with character string MPH, (b) feet/second, chosen with FPS, (c) meters/second, specified with MPS, and (d) knots, selected with KNOTS. Variable PUNITS declares the system of units for atmospheric pressure data and is applicable for hurricane wind fields only. Data can have units of millibars (MILLIBAR), feet of water (FEETH2O), meters of water (METERH2O), pounds per square inch (PSI), inches of mercury (INCHESHG), or millimeters of mercury (MMHG).

143. Strong winds that are instantaneously applied to a static water basin, such as at the start of a simulation, will generate extraneous water oscillations that can lead to the model becoming unstable, or can remain in the model solution for a significant portion of a simulation. These problems can be alleviated by gradually increasing wind magnitudes from zero at the start of the simulation, to the actual magnitude several hours into the simulation.

144. This task can be accomplished either by the user adjusting wind magnitudes entered on the TABWINDS records or by having the model feather the wind speeds internally. With feathering, the model will interpolate wind

speeds with a cubic spline function until that time specified by variable WFETHR on record WINDSPEC. This function assures that the wind speeds increase smoothly. Typical values assigned to variable WFETHR range from 1 to 3 hr.

145. Feathering can be applied to both uniform and hurricane wind fields, and also to their related constant and time-variable options. Because hotstart simulations are continuations of previous runs, feathering should not be performed for these types of simulations.

146. All TABWINDS records must immediately follow the WINDSPEC record. Furthermore, times entered on these records must correspond to the simulation's starting time defined by variable TPROV on record TIMESPEC. For the constant and time-variable options, the first TABWINDS record must occur no later than the start of the simulation. For the time-variable option, the last TABWINDS record must occur no earlier than the end of the simulation.

147. For example, if the simulation begins at 0 hr 0 min and has a duration of 36 hr, the first TABWINDS record must specify wind conditions occurring at (or before) 0 hr 0 min, and the last record must occur at 36 hr 0 min (or later). Should the simulation be continued with the hotstart option, all times entered on the TABWINDS record are referenced to the original starting time. Assuming the hotstart begins at hour 36 and has a duration of 24 hr, the first TABWINDS record must have as its time no later than 36 hr 0 min. The last TABWINDS record must have as its time 60 hr 0 min (or later).

148. WIFM uses the meteorological convention in defining wind direction: zero-deg angle defines a wind blowing from north to south, and the angles increase in value in the clockwise direction. For example, a wind blowing from east to west has an angle of 90 deg. Wind angles should not be corrected to account for the grid rotation relative to geographic direction. The model performs this task internally.

Output Specification

149. WIFM provides several options for displaying output, including: (a) numerical gage time-histories at selected grid cells (elevations, wind, and/or water velocities), (b) wind or water velocity vector fields at user-specified times during a simulation, and (c) an output listing containing an input data summary and a printout of field arrays. These data files can be

used as input to hydrodynamic models as well as wave hindcast models. Data can be displayed in either tabular or graphical form with the postprocessing package CMSPOST discussed in Appendix D of the CMS User's Manual.

150. The output listing containing a summary of the input data set is generated for every simulation. Error and warning diagnostic messages are also contained in this listing. A sample output listing containing a summary of the input data set is presented in Figure 4-13.

151. Each record is summarized in tabular form with a heading containing its record identification label followed by a brief description of that record's function. A table is composed of each variable's name, a description of that variable (including its units, when applicable), and an error diagnostic note.

152. WIFM contains error diagnostic features that inspect an input data set for possible errors. These features include: (a) comparing an inputted value against a range of quantities that are representative for that variable, (b) checking for misspelled character data, and (c) checking for missing data. The error diagnostic note can be assigned one of three character strings, which are: (a) "FATAL" for errors where the model cannot execute given the value supplied, (b) "WARN" for data that are outside the range of values typically selected for that variable, and (c) a null string for instances where an error condition has not been identified. Although this model contains error diagnostic capabilities, the user should thoroughly inspect the input data summary to ensure that the data are correct.

153. Field arrays (e.g., free surface elevations, water velocities, wind velocities, bathymetry, atmospheric pressure) are printed along with the input data summary by including one or more PRWINDOW records. Variable WPRVAR on record PRWINDOW is used to specify which field arrays are to be printed (e.g., WPRVAR = E for water surface elevations). The user can control printing of field arrays through the course of a simulation by specifying the starting (WPRSTR) and ending (WPREND) times, together with the time interval (WPRINT), at which the data will be printed. Furthermore, the user can specify printing of subgrid regions as opposed to the entire grid. This is done by specifying the x- and y-boundaries of a subgrid region with variables WXCEL1, WXCEL2, WYCEL1, and WYCEL2.

154. Gage time-histories of field arrays are saved with record RECGAGE. One RECGAGE record is required for each desired output location where the free

COASTAL MODELING SYSTEM (CMS): WIFM2D, VERSION 1.0

---- TIDE SIMULATION ----

••••• GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	•	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		•				

••••• GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	•	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		•	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	75		•	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	30	
DX	SPATIAL STEPSIZE IN X DIRECTION	500.00		•	DY	SPATIAL STEPSIZE IN Y DIRECTION	1000.00	
GLATT	LATITUDE OF GRID ORIGIN (DEGREES)	0.00		•	GLONG	LONGITUDE OF GRID ORIGIN (DEGREES)	0.00	
GALIGN	GRID ROTATION FOR EAST (DEGREES)	0.00		•				

••••• TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	•	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	30.0		•	TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	SECONDS	
TPROV	TIME AT START OF MODEL SIMULATION	0.0		•	TMAX	TOTAL TIME OF SIMULATION	86400.0	
DTGAGS	TIME INTERVAL TO SAVE GAGE DATA	360.00		•	DTHOTS	TIME INTERVAL TO SAVE HOTSTARTS	86400.00	

••••• HYDROGRAPH AND VELOCITY MEASUREMENTS: 2 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	19	16		UAVGVAVG		INLET GAGE
2	42	15		UAVGVAVG		OCEAN GAGE

••••• PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER	•	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	•	TIMES TO PRINT (SECONDS): START AT	END AT	INTERVAL	NOTES:	•	VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1	•	X= 1	X= 75	Y= 1	Y= 30		•	0.0	86400.0	3600.0		•	EV	

••••• LOCATIONS OF OPEN BOUNDARIES:

BOUNDARY NUMBER	•	LOCATION LINE:	FROM:	TO:	NOTES:	•	BOUNDARY FUNCTIONS REQUIRED TYPE:	FN1	FN2	NOTES:	•	BOUNDARY NAME:
1	•	X= 75	Y= 1	Y= 30		•	CONSTELV	1	0		•	BDRYX
2	•	Y= 1	X= 17	X= 75		•	INTRPELV	2	1		•	BDRY1
3	•	Y= 30	X= 17	X= 75		•	INTRPELV	2	1		•	BDRY2

Figure 4-13. Sample output listing

surface elevation, wind and water velocity, and atmospheric pressure fields are to be saved. A maximum of 120 gages, each containing up to 1,000 points, can be processed. All gage time-histories are stored in one file and are processed by programs HYDADD, HYDLST, and HYDPLT in package CMSPOST.

155. Variables GXPOS and GYPOS on record RECGAGE define the grid location where field arrays are saved. The time interval at which these data are stored is controlled by variable DTGAGS on record TIMESPEC. Variable GTYPE on record RECGAGE is applicable only to averaging water velocities generated by model WIFM and does not affect output from model SPH.

156. Record RECSNAPS allows the user to store wind and water velocity data for generating vector plots. The stored data can also be used as input to other models. Data can be saved at regular time intervals (SNPTYP = INTERVAL), at specific times during a simulation (SNPTYP = TIMES), or both; however, all time indices must be integer multiples of the time-step DELT. For data storage at regular time intervals, SNPSTR defines the time at which data storage is to begin, SNPEND defines the time at which data storage is to end, and SNPINT is the regular time interval at which data storage occurs. For data storage at user-specified times, one RECSNAPS record is required for each time (SNPTIM) at which a snapshot is to be recorded. All times on record RECSNAPS are in TUNITS. More than one RECSNAPS record can be used, and up to 100 snapshots can be saved in a file. These data can be processed with programs SNAPCON, SNAPLST, and SNAPVEC which reside in package CMSPOST.

157. Records XRECRANG and YRECRANG allow the user to save data describing discharges across arbitrary transects. These data allow the user to (a) check flow through various tributaries or (b) determine the tidal prism. One record is required for each desired output location. A maximum of 120 ranges, each containing up to 1,000 points, can be processed. All range time-histories are stored in one file and are processed by programs HYDADD, HYDLST, and HYDPLT in package CMSPOST.

158. Similar to barriers and boundaries, variable RPOS1 defines the x-cell position (for XRECRANG) or the y-cell position where data are to be recorded. Variables RPOS2 and RPOS3 define the range, or extent, of the recording range location. For XRECRANG, records RPOS2 and RPOS3 indicate the y-extent, and for YRECRANG records RPOS2 and RPOS3 indicate the x-extent. The time interval at which these data are stored is controlled by variable DTGAGS on record TIMESPEC. RNAME is used to name the range data.

PART V: ILLUSTRATIVE EXAMPLES

159. Five illustrative examples are included in this section to demonstrate WIFM's capabilities. The grid geometry for the first four examples is the same; however, the forcing functions vary. The 75 by 30 cell study area used in the first four examples consists of an open ocean and back-bay area joined through an inlet and two barrier islands (Figure 4-14). Boat traffic through the inlet is protected with two jetties. A small island situated in the back bay is also simulated. The examples include (a) a tidal forcing simulation without advection and diffusion terms or feathering, (b) a tidal forcing simulation starting at slack water and with nonlinear terms, (c) a wind-induced setup simulation, and (d) a river discharge simulation. Although the examples show individual applications of wind and discharge forcing functions, they can be combined and applied simultaneously. The fifth example simulates a hurricane in the Gulf of Mexico and the associated storm surge that would inundate the coastal United States. This example combines the effects of winds and tides.

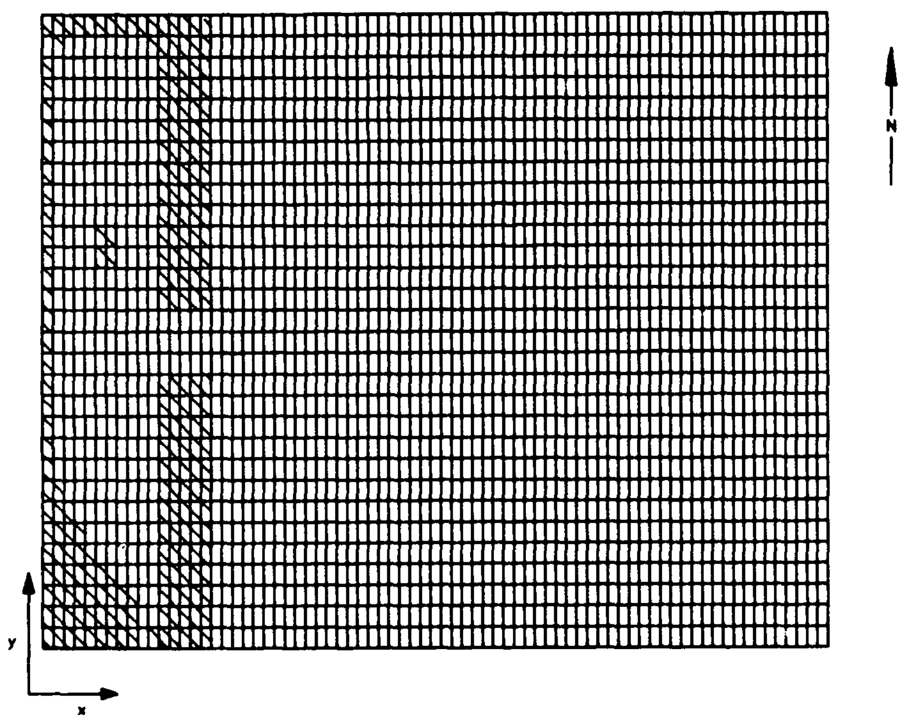


Figure 4-14. Computational grid for four examples

Tidal Forcing Simulation

160. The tidal forcing simulation was run on the 75 by 30 cell grid described previously (Figure 4-15). The grid's spatial resolution was 500 ft in the on-offshore (x-) direction and 1,000 ft in the longshore (y-) direction for an overall grid size of 37,500 by 30,000 ft. It should be noted that the grid resolution between jetties is usually much finer (more cells) than what is used in these examples, in order to properly represent inlet hydrodynamics. The water depth in the back bay was held to a constant depth of 10 ft. The water depth varied from 30 ft along the shoreline cells to 300 ft at the offshore boundary. The duration of the simulation was 24 hr.

161. A tidal forcing function was implemented along the offshore boundary (T1) using harmonic constituent data (M2 tide, amplitude = 3.97 ft, epoch = 199.02). Elevation values were spatially constant along the seaward boundary. Thus, all the seaward boundary cells acted as one entity, having the same time-series of water surface fluctuations. The tidal forcing function at the shoreline (T2) was identical to the offshore tidal forcing function, except for a 10-min phase lag. Elevation values along the

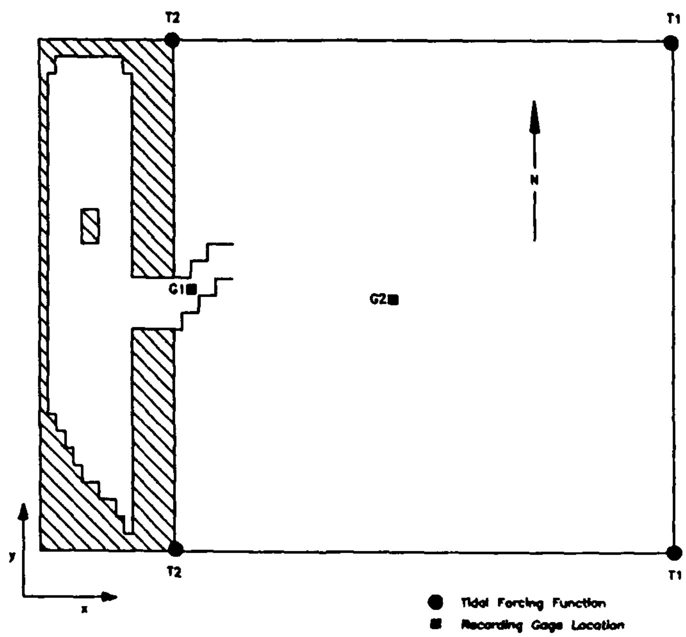


Figure 4-15. Computational area for tidal forcing simulations

lateral boundary cells were interpolated from the two forcing functions (T1 and T2) applied at the ends of the boundary segment. Tide gages were placed at two locations, in the inlet (cell (19,16)) and in the open ocean (cell (42,15)), to monitor hydrograph data.

162. The input data set is given in Table 4-6 and is discussed below. The location and type of boundary forcing functions are specified with XBOUNDRY and YBOUNDRY records. FUNCTION, CNRECORD, and CONSTIT records give specifics about the two tidal forcing functions, such as the harmonic constituent(s) used, amplitude(s), epoch(s), and time(s) of occurrence. XBARRIER and YBARRIER records were used to denote the two jetties. Record BATHSPEC is used to describe the bathymetric data, and RECGAGE records show the locations of the two recording gages. The PRWINDOW record was used to print elevations and velocities for the entire grid to the output summary file at 1-hr time intervals (Table 4-7).

163. The simulation was run for 86,400 sec (24 hr), and elevation and velocity values were saved every 360 sec at the two recording gage locations. At the conclusion of the simulation, the hydrograph data were examined to check model results (Figures 4-16 and 4-17). The water surface elevation at the inlet gage shows a slight spurious oscillation at the start of the simulation, but the oscillation diminishes within one tidal cycle. This slight "start-up" error can be virtually eliminated by applying the tidal forcing function more gradually (feathering) or by starting the simulation at slack water. (See variable FEATHR on the FUNCTION record or variable SELEV on record STARTUP.)

164. The water surface elevations at the open ocean gage oscillate with a very slight start-up error as previously described. The velocities at the open ocean gage travel in the x (90 deg) and -x (-90 deg) directions with a magnitude of approximately 1.3 ft/sec. The direction is dictated by the fact that the forcing function at the offshore boundary is spatially constant, and the bathymetric contours are straight and parallel to the shoreline. The velocities through the inlet travel diagonally across the grid (45 and -135 deg) as directed by the jetties. The peak magnitude is approximately 2.5 ft/sec.

165. In summary, an M2 tide was simulated in a typical study environment to show WIFM's ability to predict water surface fluctuations and velocities in response to the forcing function.

Table 4-6

Input Data Set for the Tidal Forcing Simulation

```
GENSPECS       WIFM SIMULATION NO. 1:  TIDE WITHOUT FEATHERING            ENGLISH
TIMESPEC      30. SECONDS       0.  86400.    360.
GRIDSPEC          ENGLISH      75       30    500.   1000.       0.     0.0     0.
PRWINDOW                                     3600.                       EV
RECGAGE         19       16        INLET GAGE
RECGAGE         42       15        OCEAN GAGE
XBOUNDRYCONSTELV         75        1       30       1         BDRYX
YBOUNDRYINTRPELV          1       17       75       2       1 BDRY1
YBOUNDRYINTRPELV         30       17       75       2       1 BDRY2
FUNCTION         1HARMCNST
CNRECORD       0.0     1981        6        1     2.5
CONSTIT         M2     3.97   199.02
FUNCTION         2HARMCNST
CNRECORD       0.0     1981        6        1  2.6667
CONSTIT         M2     3.97   199.02
XBARRIER        17       14       14      2.5                 XB1
XBARRIER        19       15       15      2.5                 XB2
XBARRIER        21       16       16      2.5                 XB3
XBARRIER        18       17       17      2.5                 XB4
XBARRIER        20       18       18      2.5                 XB5
YBARRIER        13       17       17      2.5                 YB1
YBARRIER        14       18       19      2.5                 YB2
YBARRIER        15       20       21      2.5                 YB3
YBARRIER        16       22       23      2.5                 YB4
YBARRIER        16       17       18      2.5                 YB5
YBARRIER        17       19       20      2.5                 YB6
YBARRIER        18       21       23      2.5                 YB7
BATHSPEC                                        YX      (6X,9F8.1)
   1      99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0
          99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0
          99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0
          99.0    99.0    99.0
   2      99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0   -10.0
         -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0
         -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0
          99.0    99.0    99.0
   3      99.0    99.0    99.0    99.0    99.0    99.0    99.0   -10.0   -10.0
         -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0
```

Table 4-7

Output Summary for the Tidal Forcing Simulation

COASTAL MODELING SYSTEM (CMS): WIFM2D, VERSION 1.0

--- WIFM SIMULATION NO. 1: TIDE WITHOUT FEATHERING ---

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*				

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		*	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	75		*	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	30	
DX	SPATIAL STEPSIZE IN X DIRECTION	500.00		*	DY	SPATIAL STEPSIZE IN Y DIRECTION	1000.00	
GLATT	LATITUDE OF GRID ORIGIN (DEGREES)	0.00		*	GLONG	LONGITUDE OF GRID ORIGIN (DEGREES)	0.00	
GALIGN	GRID ROTATION FOR EAST (DEGREES)	0.00		*				

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	30.0		*	TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	SECONDS	
TPROV	TIME AT START OF MODEL SIMULATION	0.0		*	TMAX	TOTAL TIME OF SIMULATION	86400.0	
DTGAGS	TIME INTERVAL TO SAVE GAGE DATA	360.00		*	DTHOTS	TIME INTERVAL TO SAVE HOTSTARTS	86400.00	

COASTAL MODELING SYSTEM (CMS): WIFM2D, VERSION 1.0

***** HYDROGRAPH AND VELOCITY MEASUREMENTS: 2 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	19	16		UAVGVAVG	.	INLET GAGE
2	42	15		UAVGVAVG		OCEAN GAGE

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER	*	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	*	TIMES TO PRINT (SECONDS): START AT	END AT	INTERVAL	NOTES:	*	VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1	*	X= 1	X= 75	Y= 1	Y= 30		*	0.0	86400.0	3600.0		*	EV	

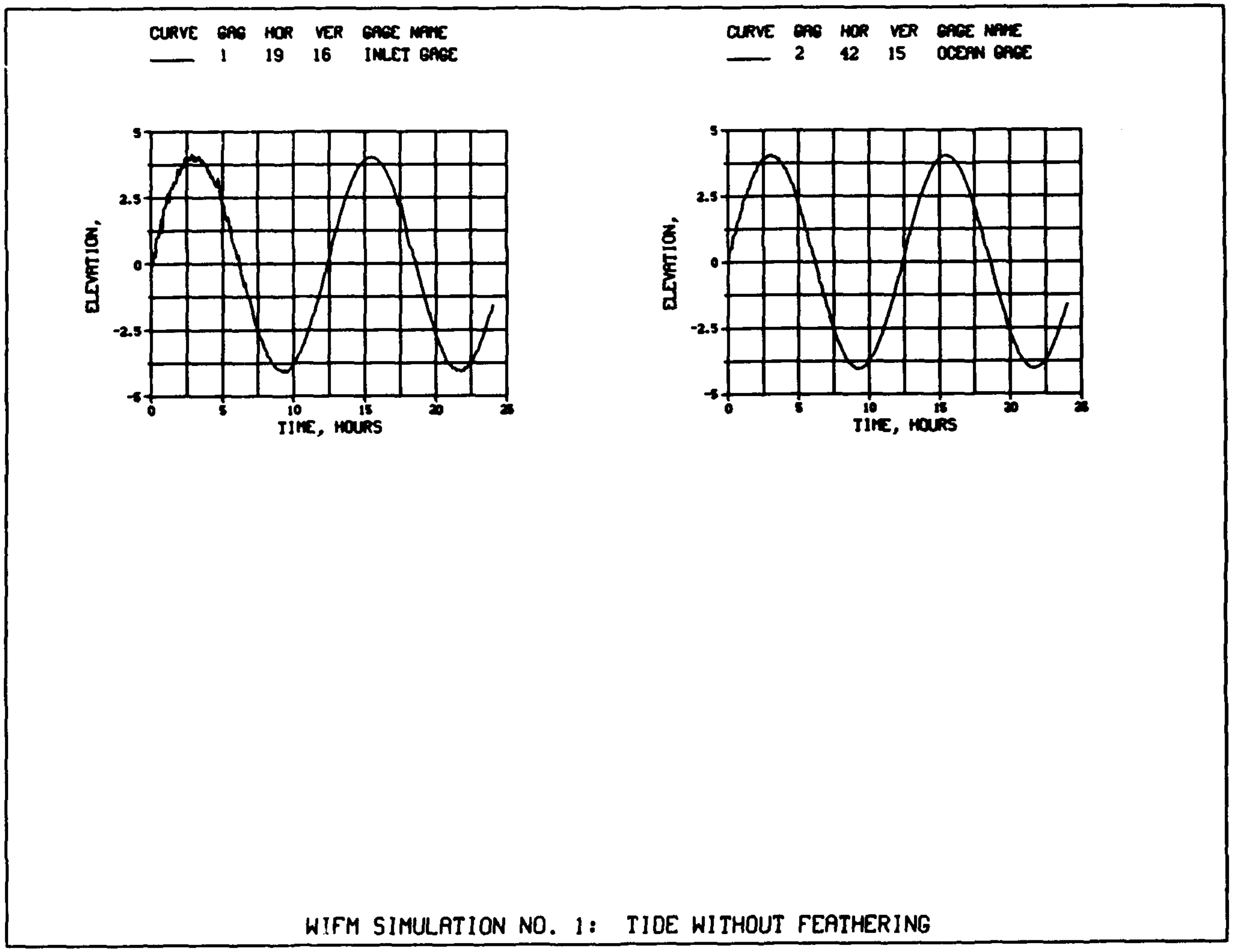


Figure 4-16. Elevation plots for the tidal forcing simulation

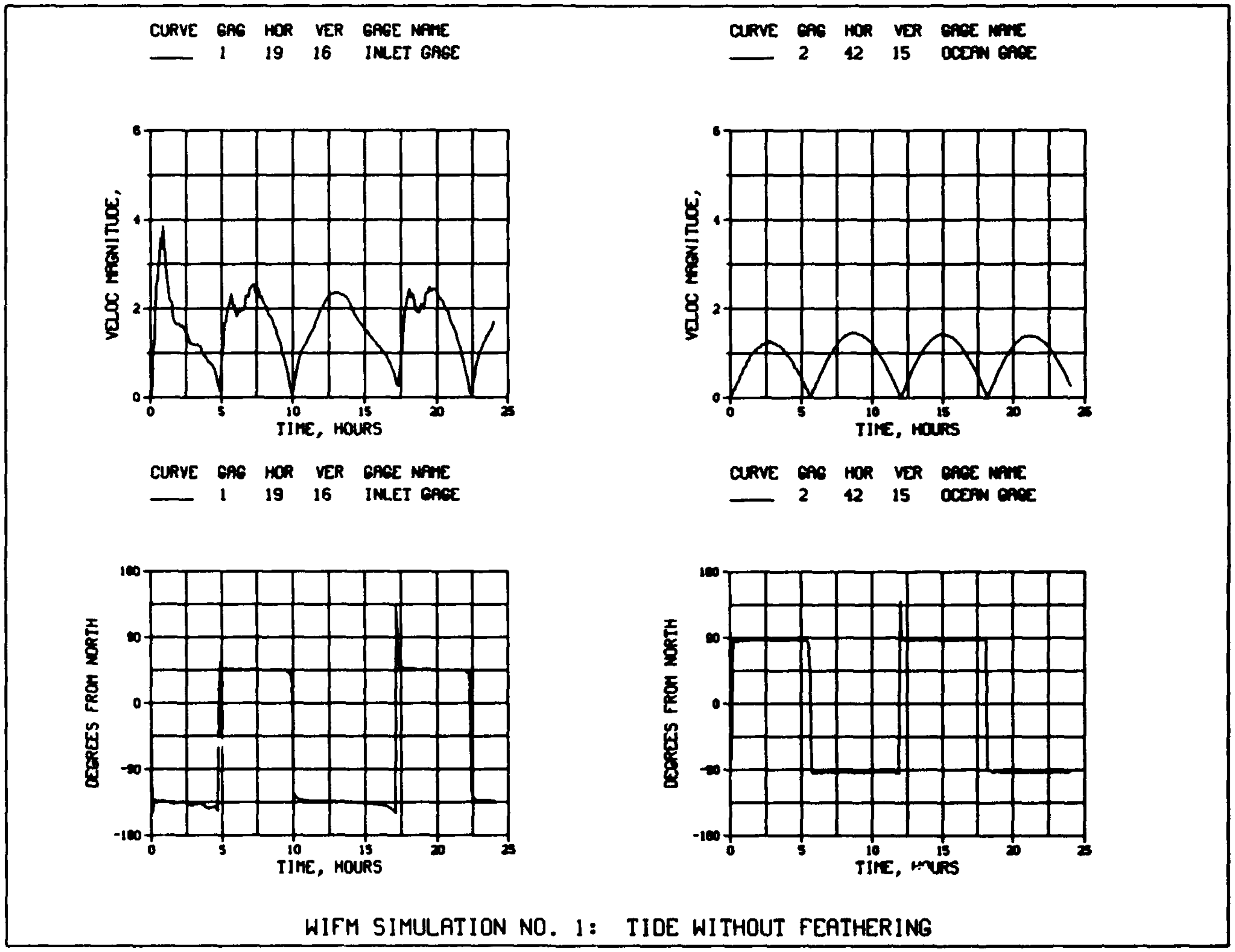


Figure 4-17. Velocity plots for the tidal forcing simulation

Tidal Forcing Simulation with Nonlinear Terms

166. The tidal forcing simulation was repeated with the addition of records ADDTERMS and STARTUP. Record ADDTERMS is used to include advective and diffusion terms in the governing equations. The nonlinear terms are more difficult and time-consuming to simulate, but provide a more realistic representation of the hydrodynamics in the study area, particularly at the inlet where velocity gradients are greatest. Record STARTUP is used to raise the entire water surface to the peak flood elevation. At peak flood (or ebb), velocities reach zero, and the initial and boundary conditions are consistent. The "start-up" error observed in the last example can be reduced considerably with this procedure. Table 4-8 shows the addition of records ADDTERMS and STARTUP to the input data set. In addition, record PRWINDOW was modified to print elevations to the output file at the conclusion of the simulation only (Table 4-9).

167. The elevation and velocity hydrographs at the inlet and open ocean gages are presented in Figures 4-18 and 4-19. The elevations do not exhibit the degree of spurious oscillation observed in the first example. Starting the simulation at slack water considerably reduced the start-up error. The velocities also appear to be different than the velocities in the first example. The magnitude of the velocity at the open ocean gage is no longer equal on the ebb and flow due to the nonlinear terms. The direction of the velocity vectors at the open ocean gage are no longer in the +x and -x-directions, but rather. have a slight y-direction component due to the nonlinear terms.

Wind-Induced Setup Simulation

168. In the third test simulation, a uniform wind was blown in the shoreward direction for the duration of the simulation (Figure 4-20). (The tidal forcing functions from the first simulation were also included.) The wind gradually increased over the first hour, until a maximum sustained wind speed of 40 knots was reached (Figure 4-21). Table 4-10 shows the addition of the WINDSPEC and TABWINDS records to the input data set to specify the gradually applied wind field. These records are used to describe the magnitude and direction of the wind field at designated times during the simulation. The PRWINDOW record was used to print elevations at hours 12 and

Table 4-8

<u>Input Data Set for the Tidal Forcing Simulation with Nonlinear Terms</u>

```
GENSPECS      WIFM SIMULATION NO. 2:  TIDE WITH NONLINEAR TERMS        ENGLISH
TIMESPEC     30. SECONDS       0.  75600.    360.
STARTUP    4.048
GRIDSPEC         ENGLISH       75      30     500.  1000.      0.     0.0    0.
PRWINDOW                                     3600.                     EV
ADDTERMS NONCONSCONSTDIF       5.      0.
RECGAGE       19      16         INLET GAGE
RECGAGE       42      15         OCEAN GAGE
XBOUNDRYCONSTELV      75       1      30       1        BDRYX
YBOUNDRYINTRPELV       1      17      75       2       1 BDRY1
YBOUNDRYINTRPELV      30      17      75       2       1 BDRY2
FUNCTION       1HARMCNST
CNRECORD     0.0    1981       6       1     5.5
CONSTIT       M2    3.97  199.02
FUNCTION       2HARMCNST
CNRECORD     0.0    1981       6       1  5.6667
CONSTIT       M2    3.97  199.02
XBARRIER      17      14      14     2.5                XB1
XBARRIER      19      15      15     2.5                XB2
XBARRIER      21      16      16     2.5                XB3
XBARRIER      18      17      17     2.5                XB4
XBARRIER      20      18      18     2.5                XB5
YBARRIER      13      17      17     2.5                YB1
YBARRIER      14      18      19     2.5                YB2
YBARRIER      15      20      21     2.5                YB3
YBARRIER      16      22      23     2.5                YB4
YBARRIER      16      17      18     2.5                YB5
YBARRIER      17      19      20     2.5                YB6
YBARRIER      18      21      23     2.5                YB7
BATHSPEC                                      YX     (6X,9F8.1)
   1      99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0
          99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0
          99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0
          99.0    99.0    99.0
   2      99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0   -10.0
         -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0
         -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0
          99.0    99.0    99.0
   3      99.0    99.0    99.0    99.0    99.0    99.0    99.0   -10.0   -10.0
         -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0
         -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0   -10.0
         -10.0    99.0    99.0
```

Table 4-9

Output Summary for the Tidal Forcing Simulation with Nonlinear Terms

COASTAL MODELING SYSTEM (CMS): WIFM2D, VERSION 1.0

— WIFM SIMULATION NO. 2: TIDE WITH NONLINEAR TERMS —

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*				

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		*	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	75		*	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	30	
DX	SPATIAL STEPSIZE IN X DIRECTION	500.00		*	DY	SPATIAL STEPSIZE IN Y DIRECTION	1000.00	
GLATT	LATITUDE OF GRID ORIGIN (DEGREES)	0.00		*	GLONG	LONGITUDE OF GRID ORIGIN (DEGREES)	0.00	
GALIGN	GRID ROTATION FOR EAST (DEGREES)	0.00		*				

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	30.0		*	TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	SECONDS	
TPROV	TIME AT START OF MODEL SIMULATION	0.0		*	TMAX	TOTAL TIME OF SIMULATION	86400.0	
DTGAGS	TIME INTERVAL TO SAVE GAGE DATA	360.00		*	DTHOTS	TIME INTERVAL TO SAVE HOTSTARTS	86400.00	

COASTAL MODELING SYSTEM (CMS): WIFM2D, VERSION 1.0

***** HYDROGRAPH AND VELOCITY MEASUREMENTS: 2 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	19	16		UAVGVAVG		INLET GAGE
2	42	15		UAVGVAVG		OCEAN GAGE

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER	*	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	*	TIMES TO PRINT (SECONDS): START AT	END AT	INTERVAL	NOTES:	*	VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1	*	X= 1	X= 75	Y= 1	Y= 30		*	0.0	86400.0	43200.0		*	E	

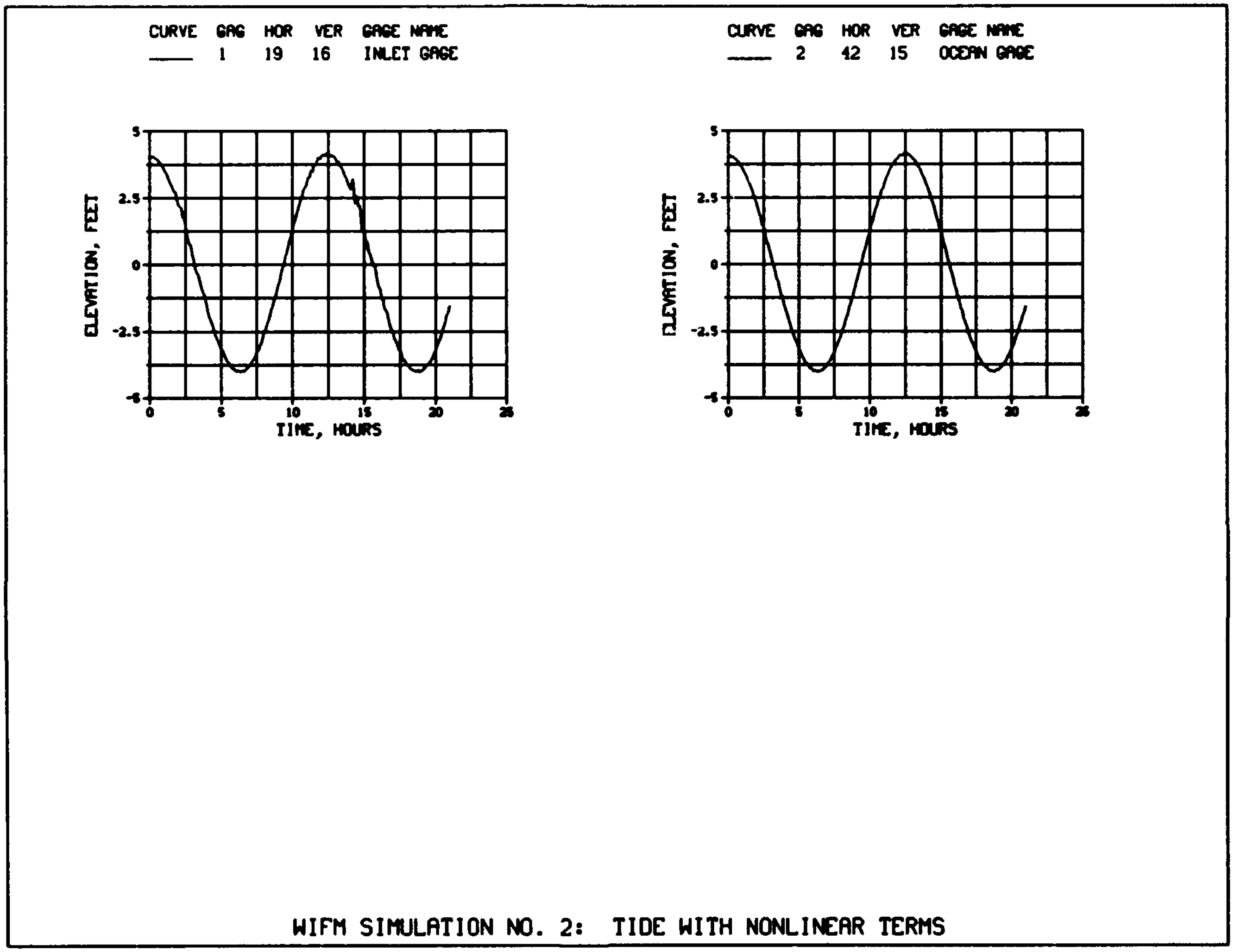


Figure 4-18. Elevation plots for the tidal forcing simulation with nonlinear terms

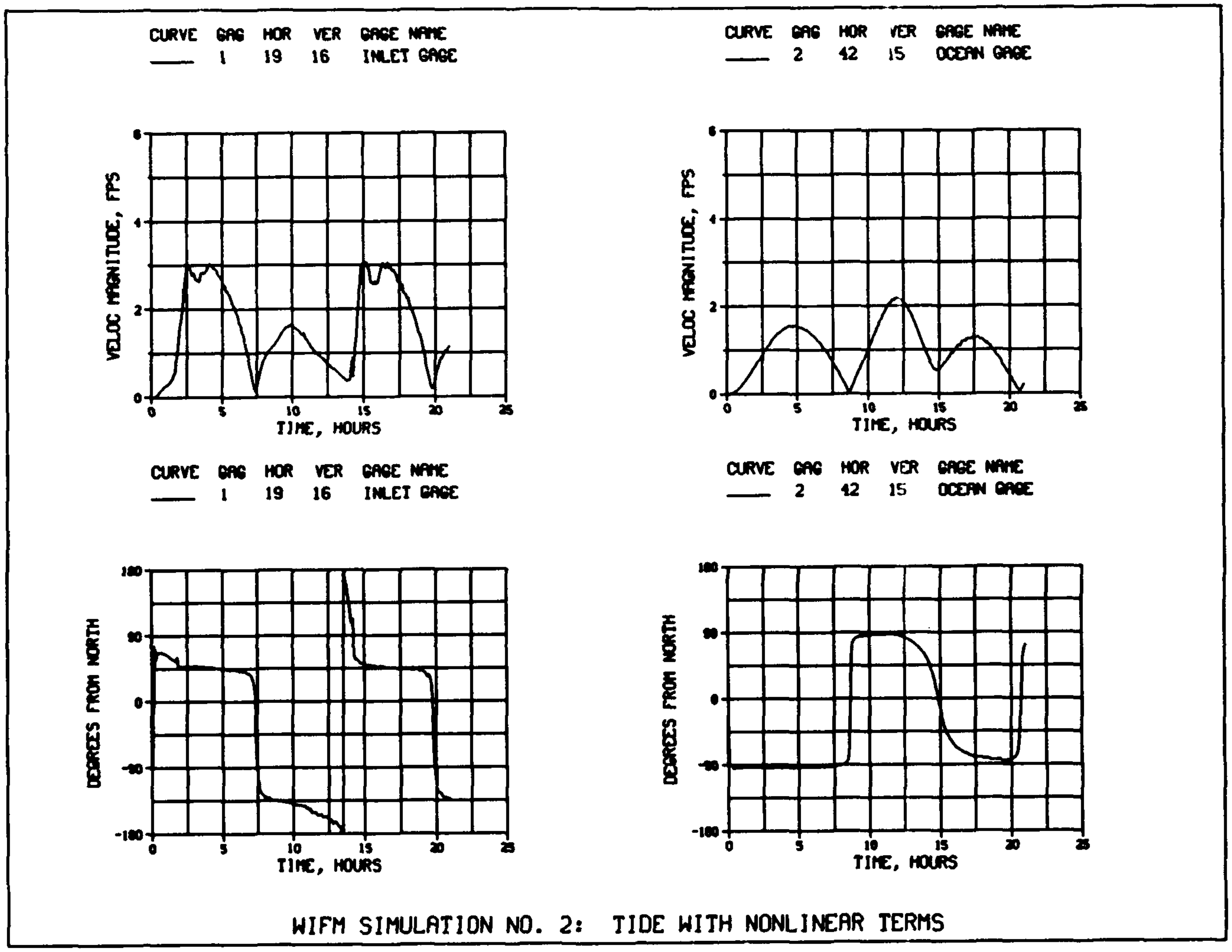


Figure 4-19. Velocity plots for the tidal forcing simulation with nonlinear terms

24 of the simulation (Table 4-11). The inlet and ocean hydrographs are presented in Figures 4-22 and 4-23 and are discussed in the following.

169. As the simulation proceeds, the wind continues to blow shoreward causing a setup to develop. From Figure 4-22 it appears that the elevations are the same for the tide with wind as with the tide alone. However, there is a slight rise in the mean water surface elevation. The magnitude of the velocities at the open ocean gage show a larger peak ebb value than peak flood value. This is caused by the tide flow and the free surface gradient created by the onshore wind being in the same or opposite directions, respectively. (The water surface slope created by the onshore wind works against the onshore propagation of the tide wave.)

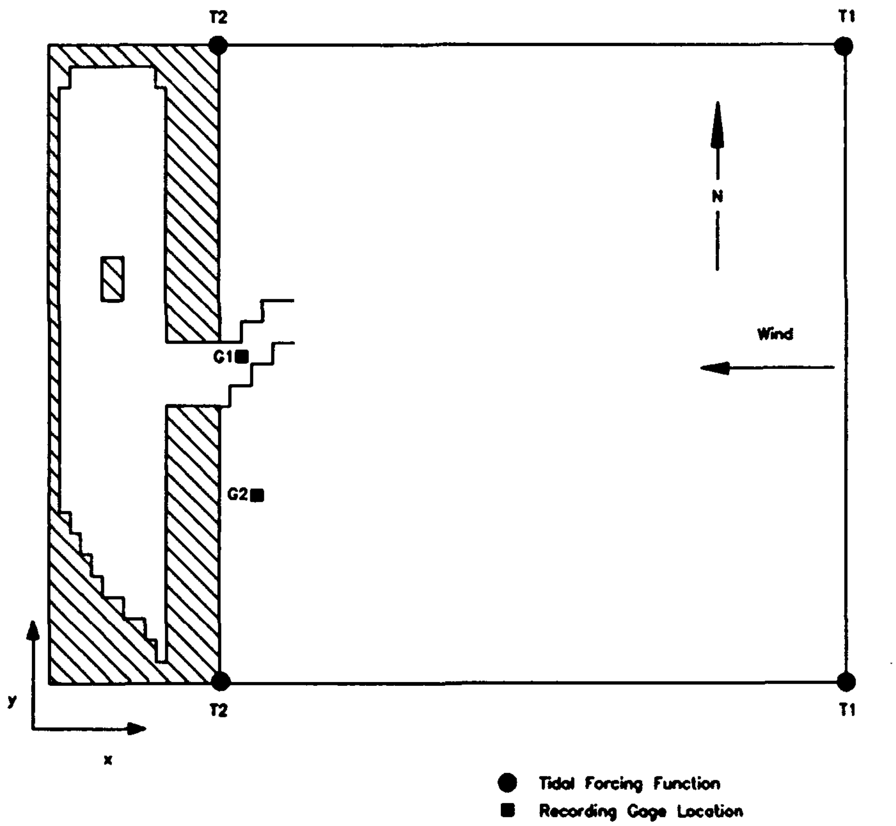


Figure 4-20. Computational grid for wind-induced setup simulation

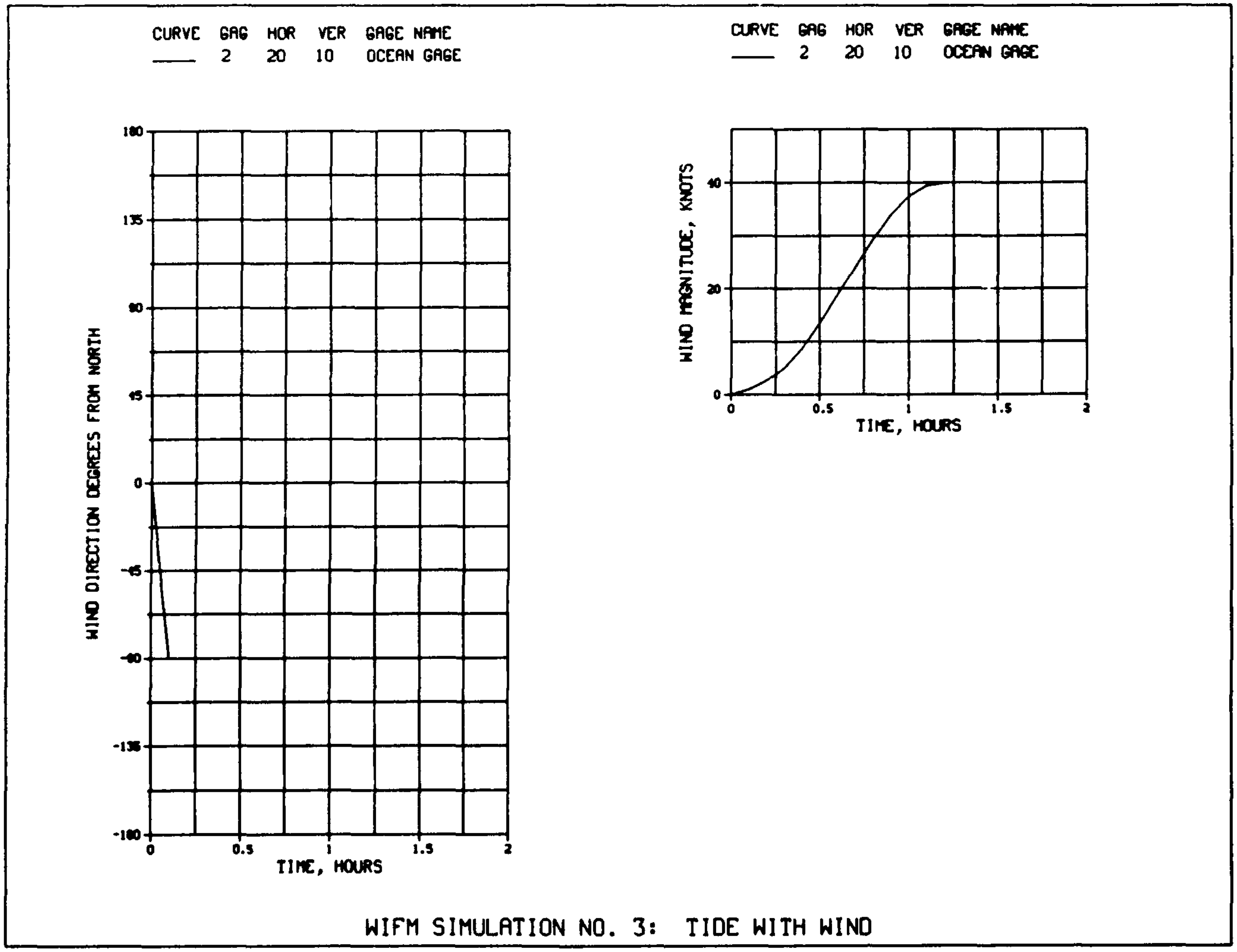


Figure 4-21. Wind magnitude and directions for wind-induced setup simulation

Table 4-10

<u>Input Data Set for the Wind-Induced Setup Simulation</u>

```
GENSPECS       WIFM SIMULATION NO. 3:  TIDE WITH WIND                 ENGLISH
TIMESPEC     30. SECONDS      0.  86400.    360.
GRIDSPEC         ENGLISH      75      30    500.  1000.      0.     0.0    0.
PRWINDOW                                  43200.                     E
WINDSPEC TABULARVARIABLE   KNOTS     PSI
TABWINDS       0.     0.0     0.0     90.
TABWINDS       0.     6.0     1.0     90.
TABWINDS       0.    10.0     2.0     90.
TABWINDS       0.    16.0     4.0     90.
TABWINDS       0.    20.0     6.0     90.
TABWINDS       0.    26.0    10.0     90.
TABWINDS       0.    42.0    24.0     90.
TABWINDS       0.    50.0    31.0     90.
TABWINDS       0.    54.0    34.0     90.
TABWINDS       0.    58.0    36.4     90.
TABWINDS       1.     2.0    38.4     90.
TABWINDS       1.     6.0    39.4     90.
TABWINDS       1.     8.0    40.0     90.
TABWINDS      24.     0.0    40.0     90.
RECGAGE       19      16         INLET GAGE
RECGAGE       20      10         OCEAN GAGE
XBOUNDRYCONSTELV      75       1      30       1        BDRYX
YBOUNDRYINTRPELV       1      17      75       2       1 BDRY1
YBOUNDRYINTRPELV      30      17      75       2       1 BDRY2
FUNCTION       1HARMCNST
CNRECORD     0.0    1981       6       1     2.5
CONSTIT       M2    3.97  199.02
FUNCTION       2HARMCNST
CNRECORD     0.0    1981       6       1  2.6667
CONSTIT       M2    3.97  199.02
XBARRIER      17      14      14     2.5                XB1
XBARRIER      19      15      15     2.5                XB2
XBARRIER      21      16      16     2.5                XB3
XBARRIER      18      17      17     2.5                XB4
XBARRIER      20      18      18     2.5                XB5
YBARRIER      13      17      17     2.5                YB1
YBARRIER      14      18      19     2.5                YB2
YBARRIER      15      20      21     2.5                YB3
YBARRIER      16      22      23     2.5                YB4
YBARRIER      16      17      18     2.5                YB5
YBARRIER      17      19      20     2.5                YB6
YBARRIER      18      21      23     2.5                YB7
BATHSPEC                                    YX     (6X,9F8.1)
   1    99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0
```

Table 4-11

Output Summary for the Wind-Induced Setup Simulation

C O A S T A L   M O D E L I N G   S Y S T E M   (C M S) :   W I F M 2 D ,   V E R S I O N   1 . 0

---- WIFM SIMULATION NO. 3: TIDE WITH WIND ----

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*				

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		*	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	75		*	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	30	
DX	SPATIAL STEPSIZE IN X DIRECTION	500.00		*	DY	SPATIAL STEPSIZE IN Y DIRECTION	1000.00	
GLATT	LATITUDE OF GRID ORIGIN (DEGREES)	0.00		*	GLONG	LONGITUDE OF GRID ORIGIN (DEGREES)	0.00	
GALIGN	GRID ROTATION FOR EAST (DEGREES)	0.00		*				

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	30.0		*	TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	SECONDS	
TPROV	TIME AT START OF MODEL SIMULATION	0.0		*	TMAX	TOTAL TIME OF SIMULATION	86400.0	
DTGAGS	TIME INTERVAL TO SAVE GAGE DATA	360.00		*	DTHOTS	TIME INTERVAL TO SAVE HOTSTARTS	86400.00	

C O A S T A L   M O D E L I N G   S Y S T E M   (C M S) :   W I F M 2 D ,   V E R S I O N   1 . 0

***** HYDROGRAPH AND VELOCITY MEASUREMENTS: 2 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	19	16		UAVGVAVG		INLET GAGE
2	42	15		UAVGVAVG		OCEAN GAGE

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER	*	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	*	TIMES TO PRINT (SECONDS): START AT	END AT	INTERVAL	NOTES:	*	VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1	*	X= 1	X= 75	Y= 1	Y= 30		*	0.0	86400.0	43200.0		*	E	

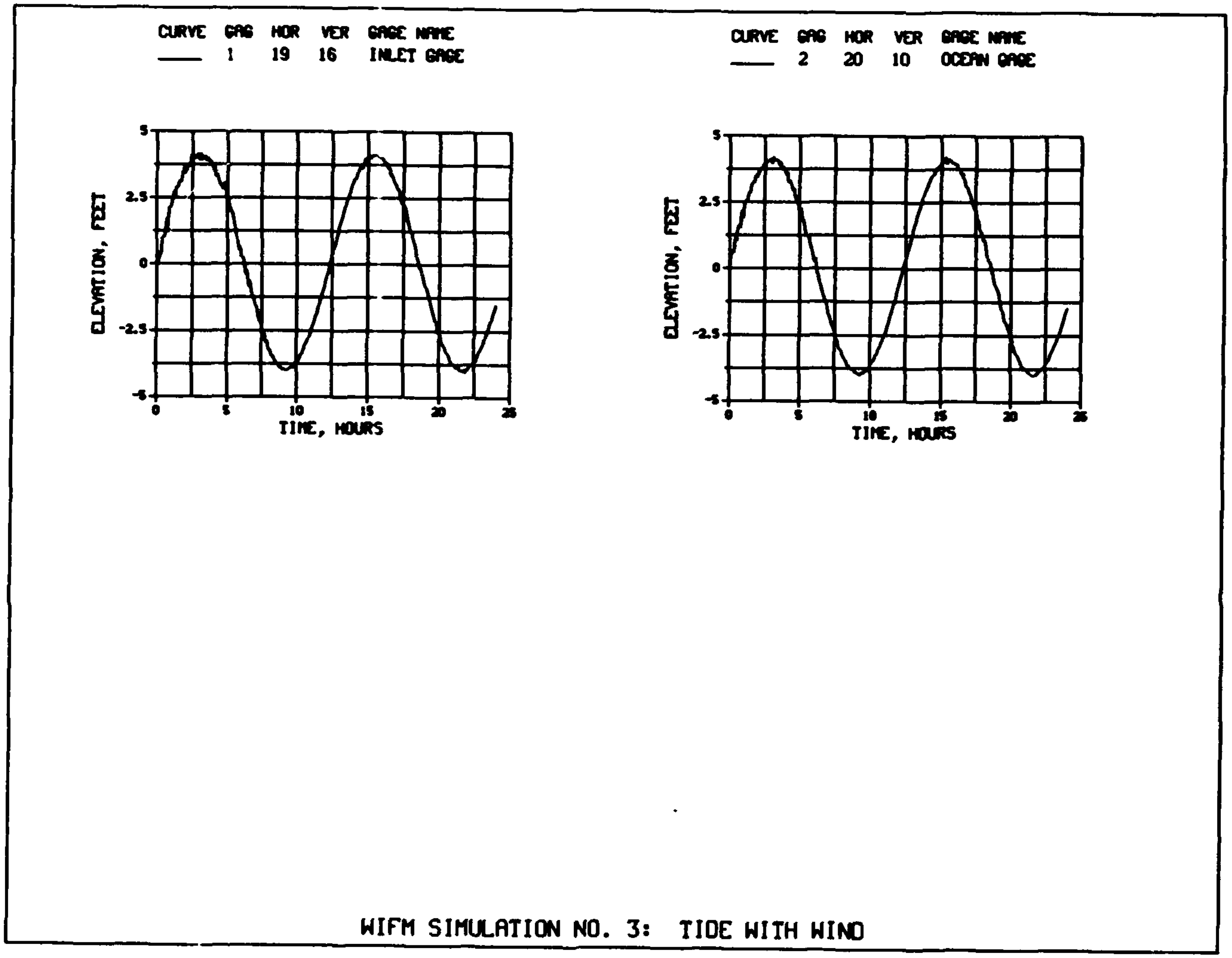


Figure 4-22. Elevation plots for the wind-induced setup simulation

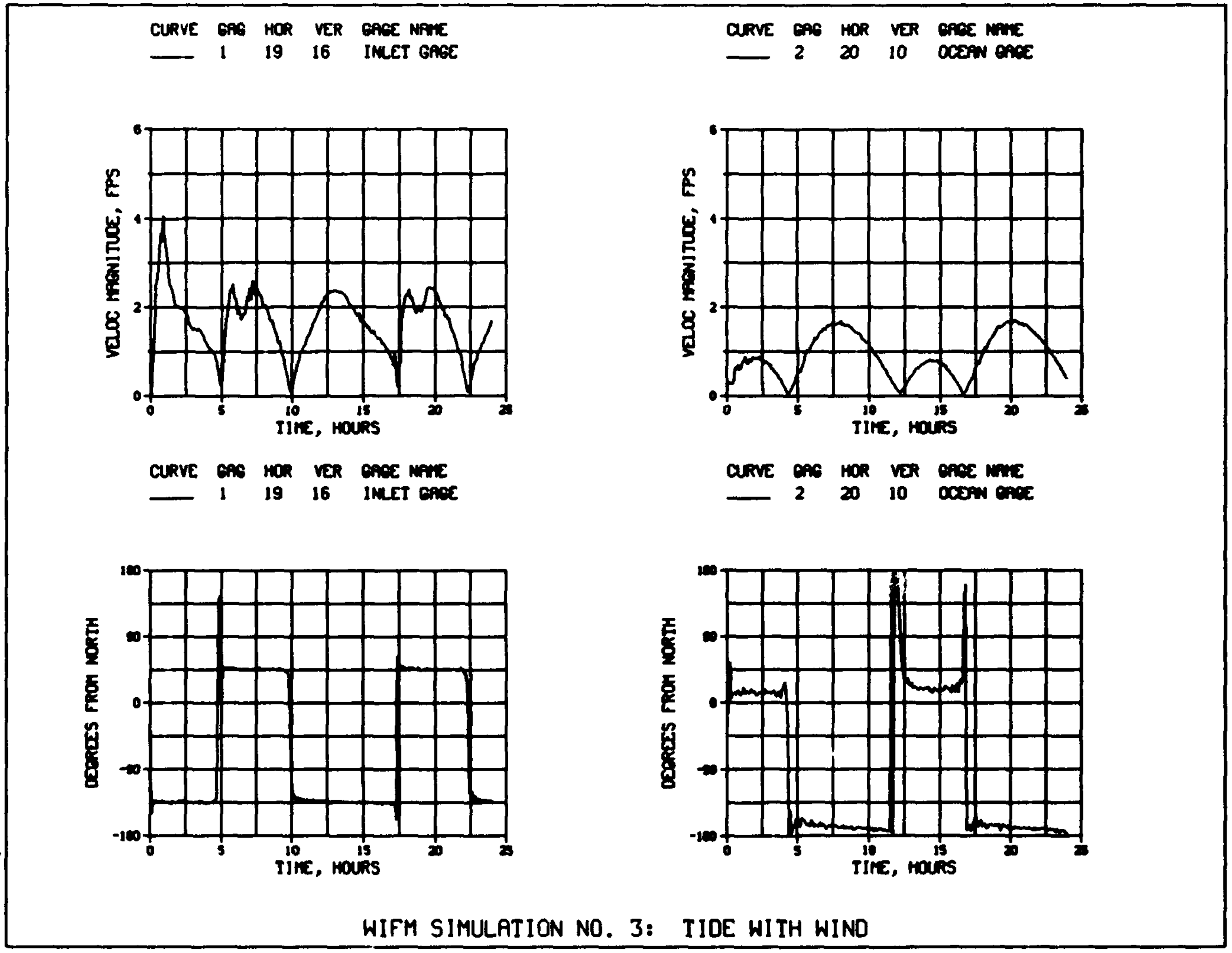


Figure 4-23. Velocity plots for the wind-induced setup simulation

River Discharge Simulation

170. In the fourth simulation, a river flowing into the back-bay area at a rate of 1,250 ft^3/sec was simulated (Figure 4-24). (The tidal forcing functions from the first simulation were also included.) The river inflow gradually increased over the first hour, until a maximum sustained flow rate of 1,250 ft^3/sec was reached. Table 4-12 shows the addition of a FUNCTION, TFRECORD, and several TABFLOW records to the input data set to specify the tabular flow forcing function. These records are used to specify inflow velocities at designated times during the simulation. An additional RECGAGE record was placed near the river mouth for monitoring purposes. The PRWINDOW record was used to print elevations at hours 12 and 24 for the simulation (Table 4-13). The inlet, ocean, and river hydrographs are presented in Figures 4-25 through 4-27 and are discussed below.

171. From Figure 4-25 it appears that the elevations at all three gages are dominated by the tidal forcing functions. The velocities at the open ocean and inlet gages are dominated by the tidal forcing (Figure 4-26); however, the river gage shows little effect of the tidal forcing function (Figure 4-27). Velocities are dominated by the river inflow.

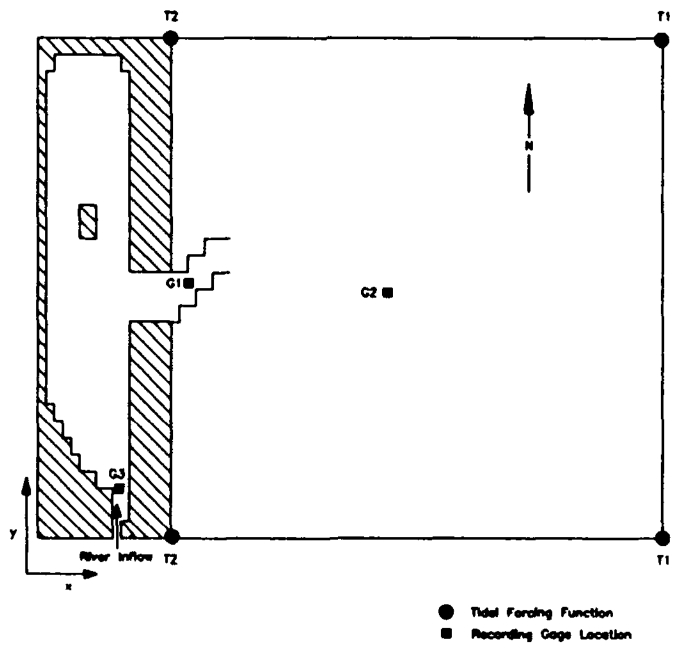


Figure 4-24. Computational grid for the river discharge simulation

Table 4-12

Input Data Set for the River Discharge Simulation

```
GENSPECS        WIFM SIMULATION NO. 4:  TIDE WITH RIVER DISCHARGE        ENGLISH
TIMESPEC      30. SECONDS      0.  86400.    360.
GRIDSPEC          ENGLISH      75       30   500.   1000.       0.      0.0    0.
PRWINDOW                                    43200.                       E
RECGAGE        19       16         INLET GAGE
RECGAGE        42       15         OCEAN GAGE
RECGAGE        10        4         RIVER GAGE
XBOUNDRYCONSTELV        75      1       30        1         BDRYX
YBOUNDRYCONSTDIS         1     10       10        3         RIVER
YBOUNDRYINTRPELV         1     17       75        2       1 BDRY1
YBOUNDRYINTRPELV        30     17       75        2       1 BDRY2
FUNCTION         1HARMCNST
CNRECORD      0.0     1981      6        1      2.5
CONSTIT        M2     3.97  199.02
FUNCTION         2HARMCNST
CNRECORD      0.0     1981      6        1   2.6667
CONSTIT        M2     3.97  199.02
FUNCTION         3TABFLOWS
TFRECORD       14        3IRREGINT
TABFLOW        0.      0.0      0.     0.0
TABFLOW        0.      6.0      0. 0.00625
TABFLOW        0.     10.0      0.  0.0125
TABFLOW        0.     16.0      0.   0.025
TABFLOW        0.     20.0      0.  0.0375
TABFLOW        0.     26.0      0.  0.0625
TABFLOW        0.     42.0      0.    0.15
TABFLOW        0.     50.0      0. 0.19375
TABFLOW        0.     54.0      0.  0.2125
TABFLOW        0.     58.0      0.  0.2275
TABFLOW        1.      2.0      0.    0.24
TABFLOW        1.      6.0      0. 0.24625
TABFLOW        1.      8.0      0.    0.25
TABFLOW       24.      0.0      0.    0.25
XBARRIER       17       14      14     2.5                XB1
XBARRIER       19       15      15     2.5                XB2
XBARRIER       21       16      16     2.5                XB3
XBARRIER       18       17      17     2.5                XB4
XBARRIER       20       18      18     2.5                XB5
YBARRIER       13       17      17     2.5                YB1
YBARRIER       14       18      19     2.5                YB2
YBARRIER       15       20      21     2.5                YB3
YBARRIER       16       22      23     2.5                YB4
YBARRIER       16       17      18     2.5                YB5
YBARRIER       17       19      20     2.5                YB6
YBARRIER       18       21      23     2.5                YB7
BATHSPEC                                     YX      (6X,9F8.1)
      1    99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0    99.0
```

Table 4-13
Output Summary for the River Discharge Simulation

COASTAL MODELING SYSTEM (CMS): WIFM2D, VERSION 1.0

---- WIFM SIMULATION NO. 4: TIDE WITH RIVER DISCHARGE ----

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	* VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*			

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	* VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		* GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	75		* YCELL	NUMBER OF GRID CELLS, Y DIRECTION	30	
DX	SPATIAL STEPSIZE IN X DIRECTION	500.00		* DY	SPATIAL STEPSIZE IN Y DIRECTION	1000.00	
GLATT	LATITUDE OF GRID ORIGIN (DEGREES)	0.00		* GLONG	LONGITUDE OF GRID ORIGIN (DEGREES)	0.00	
GALIGN	GRID ROTATION FOR EAST (DEGREES)	0.00		*			

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	* VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	30.0		* TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	SECONDS	
TPROV	TIME AT START OF MODEL SIMULATION	0.0		* TMAX	TOTAL TIME OF SIMULATION	86400.0	
DTGAGS	TIME INTERVAL TO SAVE GAGE DATA	360.00		* DTHOTS	TIME INTERVAL TO SAVE HOTSTARTS	86400.00	

COASTAL MODELING SYSTEM (CMS): WIFM2D, VERSION 1.0

***** HYDROGRAPH AND VELOCITY MEASUREMENTS: 3 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	19	16		UAVGVAVG		INLET GAGE
2	42	15		UAVGVAVG		OCEAN GAGE
3	10	4		UAVGVAVG		RIVER GAGE

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER	*	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	*	TIMES TO PRINT (SECONDS): START AT	END AT	INTERVAL	NOTES:	*	VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1	*	X= 1	X= 75	Y= 1	Y= 30		*	0.0	86400.0	43200.0		*	E	

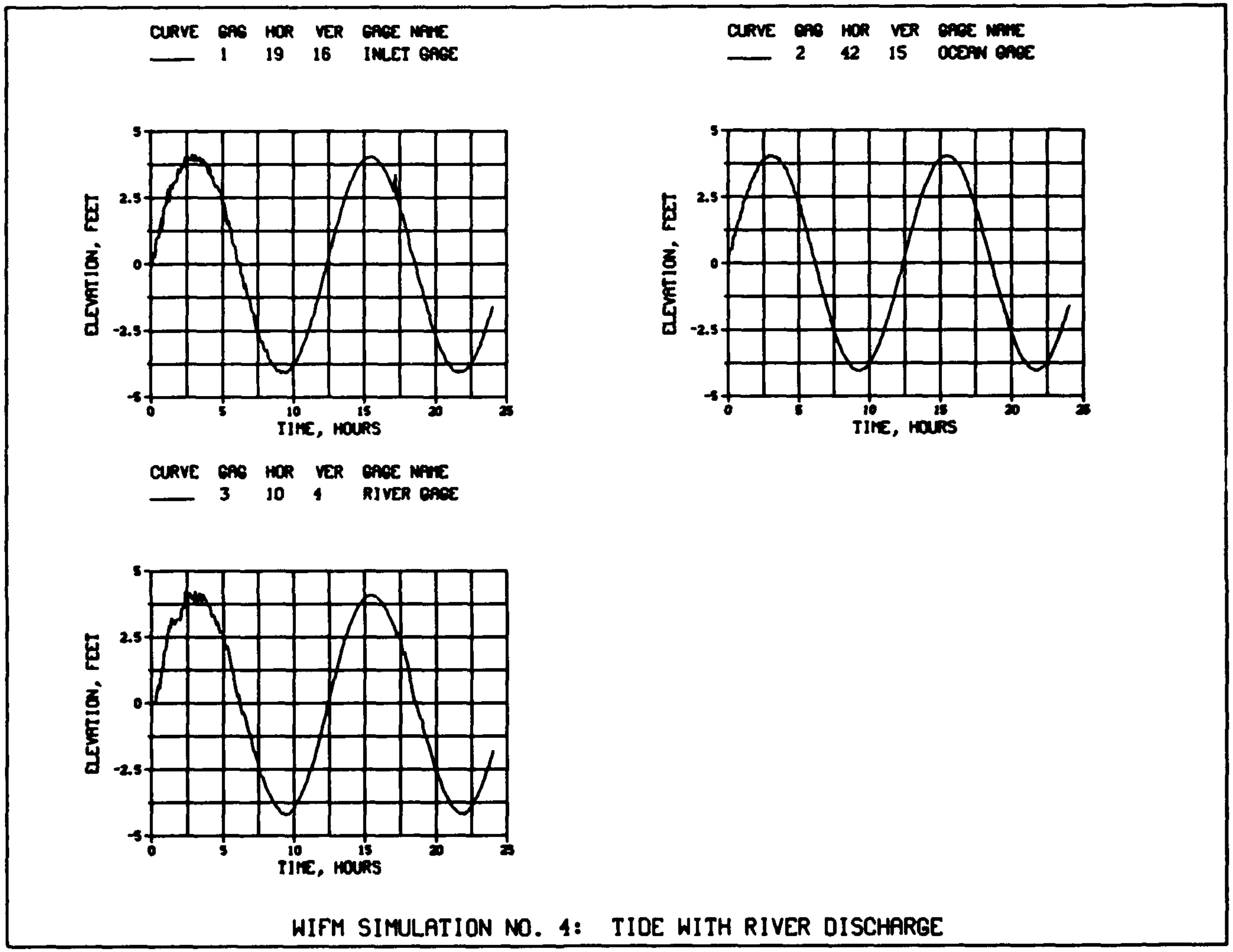


Figure 4-25. Elevation plots for the river discharge simulation

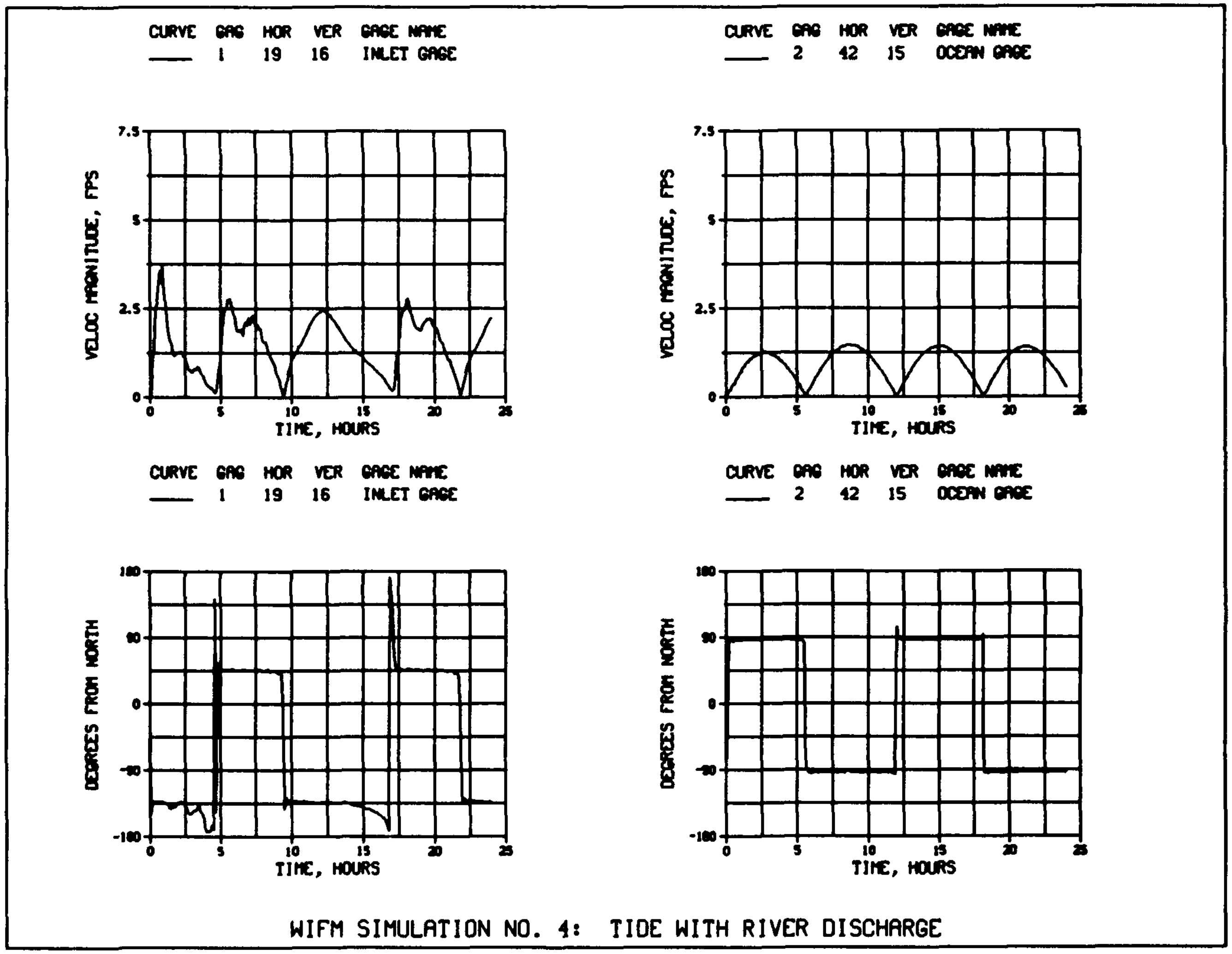


Figure 4-26. Velocity plots for the wind-induced setup simulation, gages 1 and 2

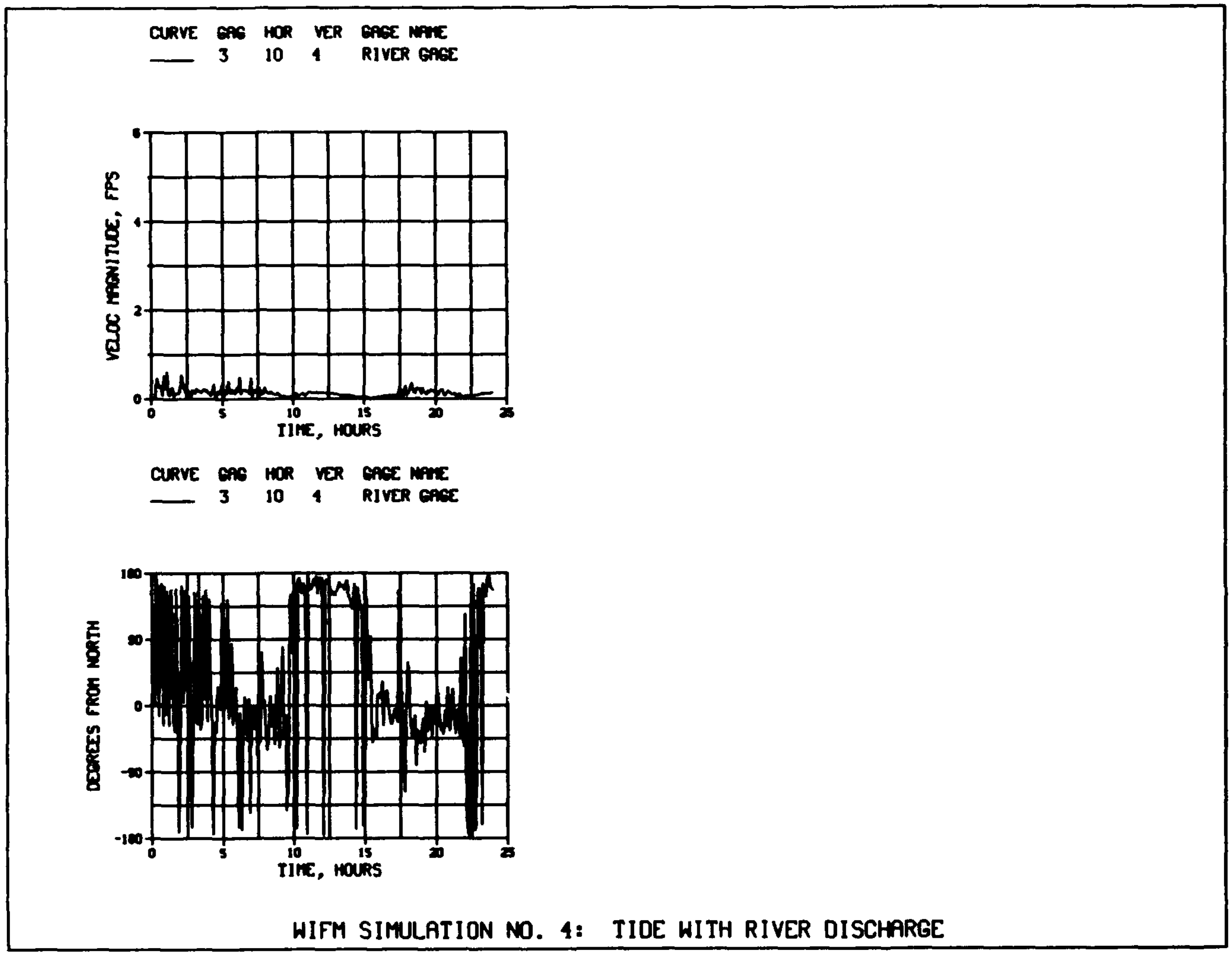


Figure 4-27. Velocity plot for the wind-induced setup simulation, gage 3

Storm Surge Example

172. The final example simulates a hurricane in the Gulf of Mexico and the associated storm surge that would inundate the coastal United States. The study area extends in the longshore direction from Sabine Lake, Louisiana, to the Mississippi River mouth (Figure 4-28). The grid's northern boundary was chosen so that Grand Lake and Vermilion Bay are included in the model, and the southern boundary extends beyond the Continental Shelf.

173. The grid's origin was arbitrarily chosen at its southwest corner. (Any of the four corners can be chosen as the origin.) Thus, the x-axis corresponds with the longshore axis, and the y-axis extends in the landward direction. The grid covers approximately 335 n.m. in the x-direction and 160 n.m. in the y-direction and is aligned at an angle of 340.0 deg, measured counterclockwise from east to the x-axis. At this angle, the x-axis roughly parallels the shoreline, providing a smooth representation of the land-water interface. Alignments that produce jagged, "saw-tooth" shorelines should be avoided because surface friction effects would not be properly imposed on the wind field. The grid is composed of 194 cells in the x-direction and 96 cells in the y-direction, with a variable cell width. Greater resolution is needed, particularly in the bay areas, to accurately represent the hydraulic features influencing currents and water levels. Typically, a grid used for hydrodynamic modeling has cell widths of 100 to 500 ft in channel and inlet areas, and cell widths of approximately 10,000 ft along the outer seaward boundary. Additional guidance in generating grids is contained in Appendix A of the *CMS User's Manual*.

174. This problem is a hindcast simulation of a hypothetical hurricane striking the Louisiana coast. Figure 4-29 illustrates the track of the hypothetical hurricane as it travels across the Gulf of Mexico and the southern United States.

175. The simulation began at 0000 GMT 14 August 1985 and concluded 48 hr later at 0000 GMT 16 August 1985. The hurricane reached landfall at approximately 1630 GMT 15 August 1985, or at simulation time 40 hr. The simulation was started 40 hr before landfall so that the model would have sufficient time in which to develop accurate circulation fields. In addition, starting with low wind velocities would prevent the formation of artificial waves induced by shocking the model with high wind velocities.

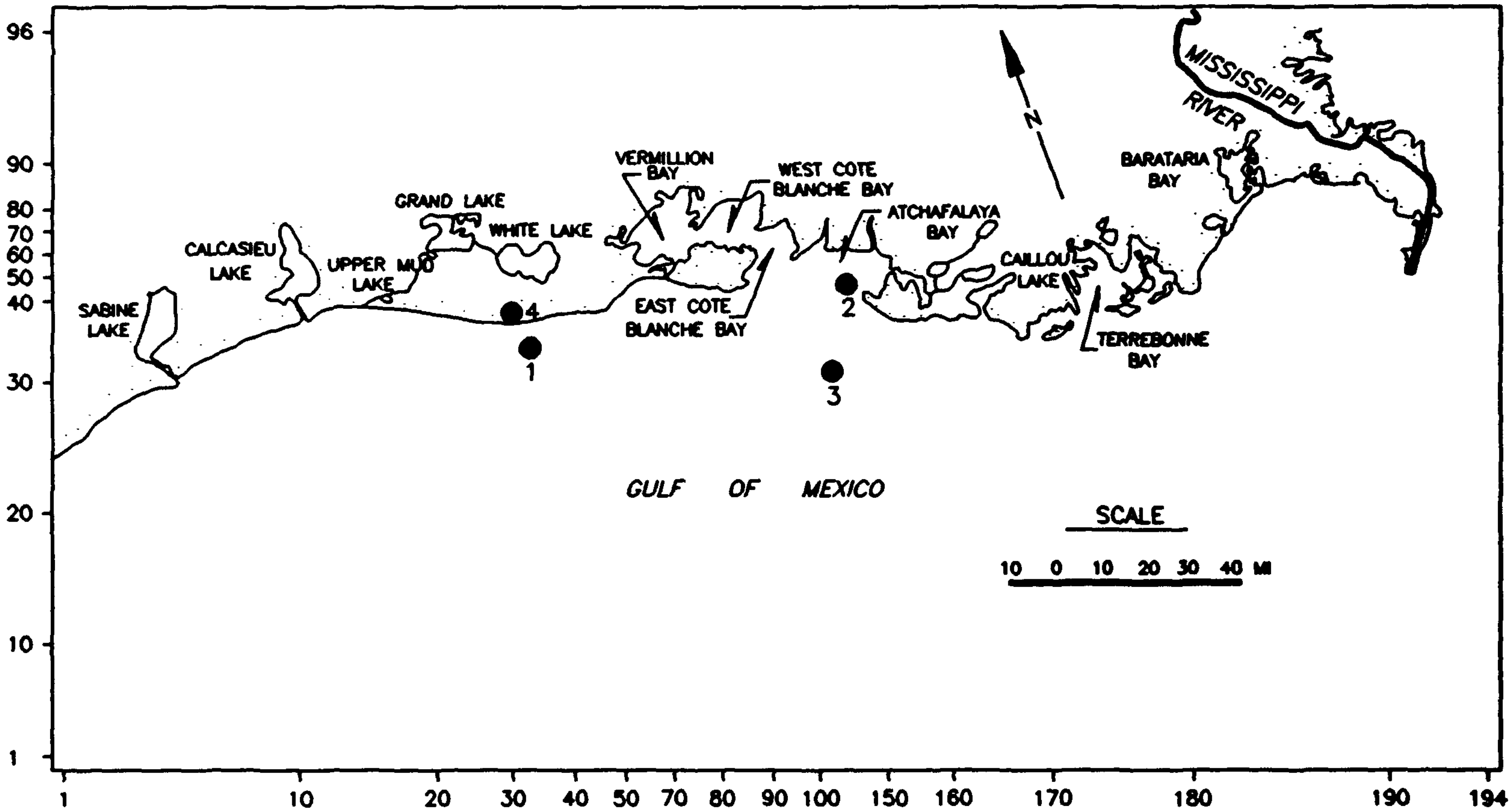


Figure 4-28. Study area for the storm surge example

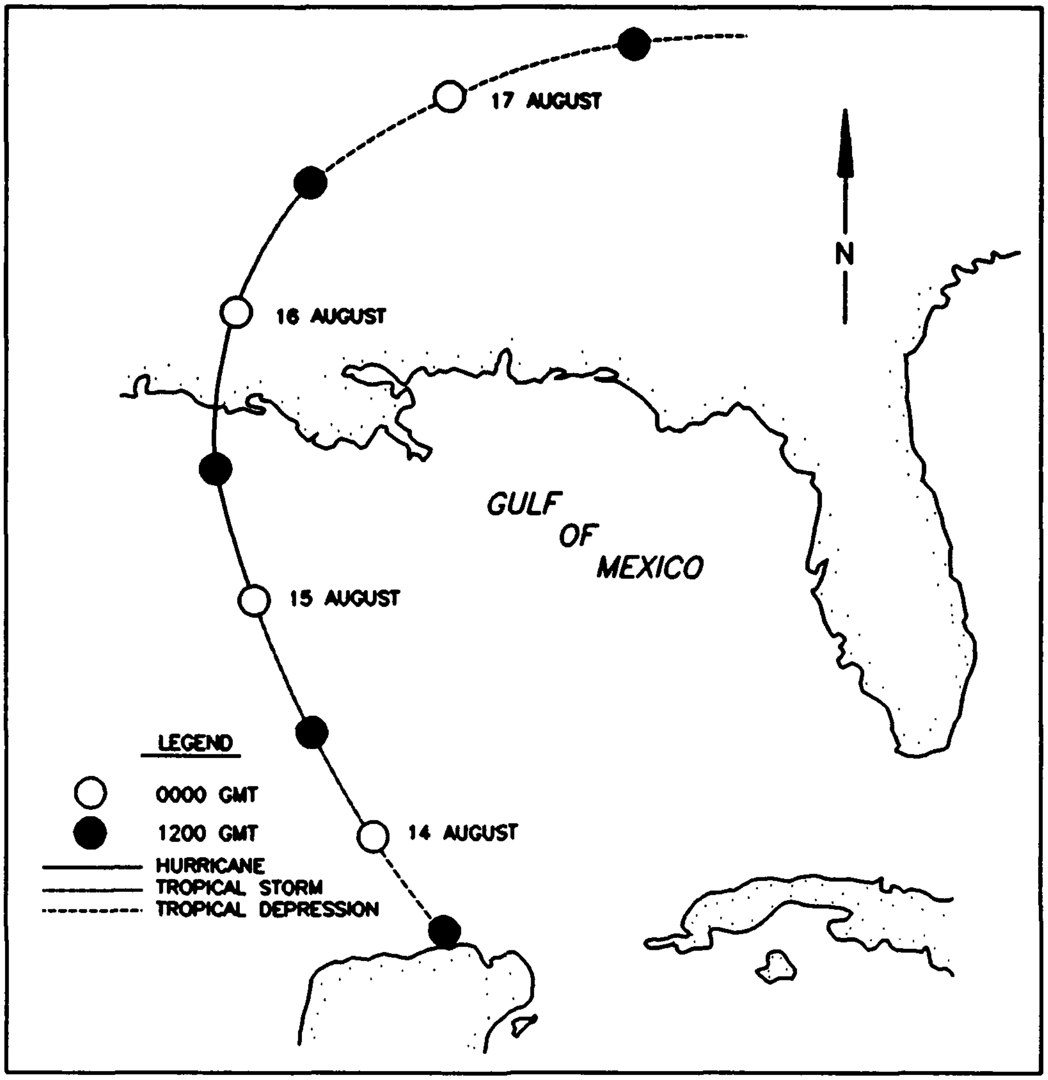


Figure 4-29. Path of the hypothetical hurricane, traveling across Gulf of Mexico and southern United States

176. For the first 18 hr during the simulation, the hurricane could be classified as a tropical storm with wind speeds increasing from 35 knots, at 0000 GMT 14 August 1985, to 60 knots at 1800 GMT 14 August 1985. During this period, its forward speed remained fairly steady within the range of 11.5 to 12.4 knots, while its central pressure dropped from 1,010 to 1,001 mb.

177. At 0000 GMT 15 August 1985, having wind speeds of 70 knots, the hurricane could be classified as a category 1 hurricane on the Saffir-Simpson scale. Central pressure steadily dropped from 997 to 987 mb at the time of landfall, and wind speeds increased 80 knots. For the next 20 hr, the

hurricane steadily lost intensity as it moved inland, with maximum wind speeds diminishing to 30 knots, and the central pressure increased to 1,000 mb. A summary of hurricane parameters in presented in Table 4-14.

Table 4-14

Hurricane Parameters

Date	Time GMT	Position Lat	Position Long	CPI mb	Wind knots
8/14	0000	23.7	90.0	1010	35
8/14	0600	24.4	90.3	1007	45
8/14	1200	25.1	90.6	1004	50
8/14	1800	25.9	91.0	1001	60
8/15	0000	26.8	91.5	997	70
8/15	0600	27.8	92.2	995	75
8/15	1200	28.9	92.6	988	80
8/15	1630	29.6	92.7	987	80
8/15	1800	30.0	92.7	988	70
8/16	0000	31.0	92.4	992	50

178. This test problem's input data set is presented in Table 4-15, and the output summary is given in Table 4-16. Uniform flux boundary conditions were specified on the lateral boundaries to allow inflow and outflow from the computational domain. The offshore boundary was specified by interpolating between six tidal forcing functions because tidal amplitudes and phases can vary significantly along an extensive study area. Hydrographs for four gage locations are given in Figure 4-30. Gage 1 is in the direct path of the hurricane and experiences a greater surge elevation than gages 2 and 3. Gage 4 is located on land to show flooding as the storm surge inundates the area. Figure 4-31 shows the wind speed and direction along with the pressure head experienced at gage 1.

Table 4-15

<u>Input Data Set for the Storm Surge Simulation</u>

```
GENSPECS                      STORM SURGE EXAMPLE
ENGLISH
GRIDSPECVARIABLE ENGLISH     194       96 38216.3 38216.3    28.6 94.6667
343.00
TIMESPEC    60.0 SECONDS     0.0 172800.     900. 172800.
PRWINDOW     100      118     40       50  21600.  21600.                EV
RECGAGE       33       33     UV STATION 1
RECGAGE      126       48     UV STATION 2
RECGAGE      107       31     UV STATION 3
RECGAGE       30       38     UV STATION 4
FDRYSPEC     15.     -15.    0.4     300.     300.     4.0   0.200
XBOUNDRYUNIFLUX       193      2       79                              EAST OPEN
XBOUNDRYUNIFLUX         1      2       25                              WEST OPEN
YBOUNDRYINTRPELV        1      1        8        1       2             SOUTH SEA
YBOUNDRYINTRPELV        1      8       35        2       3
YBOUNDRYINTRPELV        1     35      155        3       4
YBOUNDRYINTRPELV        1    155      177        4       5
YBOUNDRYINTRPELV        1    177      194        5       6
WINDSPEC     SPHVARIABLE   KNOTSMILLIBAR    900.0
SPHSPEC 1014.000     15.0   60.0    168.0     11.7
TABSPH       00.      00. 23.700   90.000 1010.00     60.0    35.0 121.0     15.0
TABSPH       06.      00. 24.400   90.300 1007.00     60.0    45.0 121.0     15.0
TABSPH       12.      00. 25.100   90.600 1004.00     60.0    50.0 121.0     15.0
TABSPH       18.      00. 25.900   91.000 1001.00     60.0    60.0 121.0     15.0
TABSPH       24.      00. 26.800   91.500  997.00     50.0    70.0 121.0     15.0
TABSPH       30.      00. 27.8     92.2    995.00     45.0    75.0 121.0     15.0
TABSPH       36.      00. 28.9     92.6    988.00     40.0    80.0 120.0     15.0
TABSPH       40.      30. 29.6     92.7    987.00     40.0    80.0 119.0     15.0
TABSPH       42.      00. 30.0     92.7    988.00     40.0    70.0 119.0     15.0
TABSPH       48.      00. 31.000   92.400  992.00     37.0    50.0 119.0     15.0
TABSPH       54.      00. 32.000   92.000  997.00     37.0    40.0 119.0     15.0
TABSPH       60.      00. 32.900   91.400 1000.00     37.0    30.0 119.0     15.0
FUNCTION       1HARMCNST    FEET      1.3      0.0     0.0     0.0
CNRECORD    94.6     1985      8       14      0.0 PHY.COR.AND TIME OF
CONSTITU.
CONSTIT       O1     0.50   18.8
CONSTIT       K1     0.52   26.8
CONSTIT       P1     0.15   19.8
CONSTIT       M2     0.23  258.9
CONSTIT       S2     0.08  239.5

FRICTION MANNING QUADRATVARYBATH
FRICTABL   0.025   -300.0
FRICTABL   0.025   -100.0
FRICTABL   0.025    -30.0
FRICTABL   0.025     -1.0
FRICTABL   0.025      3.0
```

Table 4-16

Output Summary for the Storm Surge Simulation

C O A S T A L   M O D E L I N G   S Y S T E M   (C M S) :   W I F M 2 D ,   V E R S I O N   1 . 0

---- WIFM SIMULATION NO. 2: TIDE WITH NONLINEAR TERMS ----

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*				

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		*	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	75		*	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	30	
DX	SPATIAL STEPSIZE IN X DIRECTION	500.00		*	DY	SPATIAL STEPSIZE IN Y DIRECTION	1000.00	
GLATT	LATITUDE OF GRID ORIGIN (DEGREES)	0.00		*	GLONG	LONGITUDE OF GRID ORIGIN (DEGREES)	0.00	
GALIGN	GRID ROTATION FOR EAST (DEGREES)	0.00		*				

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	30.0		*	TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	SECONDS	
TPROV	TIME AT START OF MODEL SIMULATION	0.0		*	TMAX	TOTAL TIME OF SIMULATION	75600.0	
DTGAGS	TIME INTERVAL TO SAVE GAGE DATA	360.00		*	DTHOTS	TIME INTERVAL TO SAVE HOTSTARTS	75600.00	

***** ADDTERMS CARD: SPECIFICATION OF ADDITIONAL TERMS IN GOVERNING EQUATIONS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
ADVTYP	GOVERNS USE OF ADVECTION TERMS	NONCONS		*	DIFTYP	GOVERNS USE OF DIFFUSION TERMS	CONSTDIF	
DIFCOF	DIFFUSION COEFFICIENT	5.0000		*	ADMASS	WATER MASS FLUX INTO SYSTEM	0.0000	

***** STARTUP CARD: SPECIFICATION OF INITIAL CONDITIONS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SELEV	INITIAL WATER SURFACE ELEVATION	4.048		*	SECHO	AMOUNT OF INPUT DATA TO BE PRINTED	SHORT	

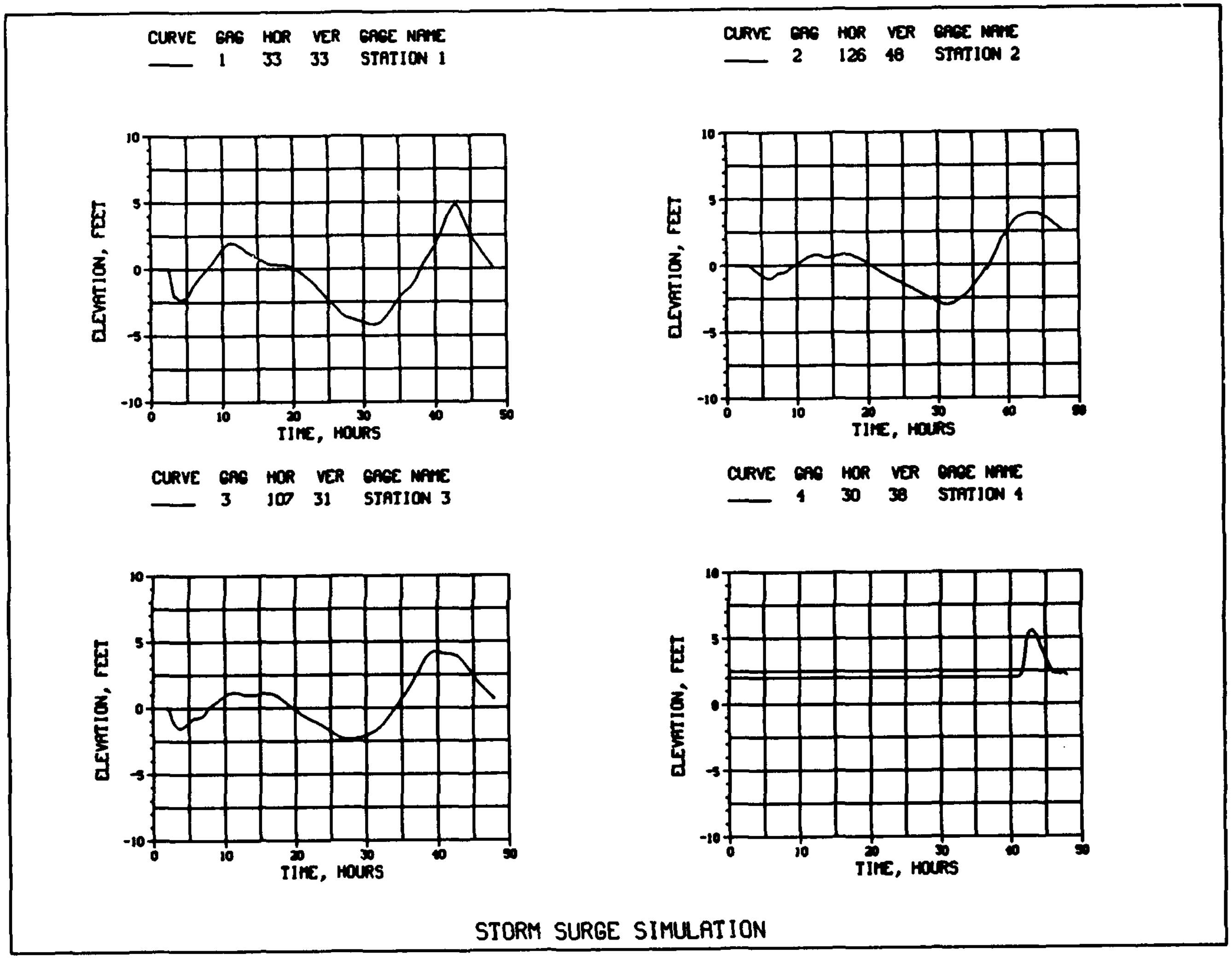


Figure 4-30. Elevation plots for the storm surge simulation

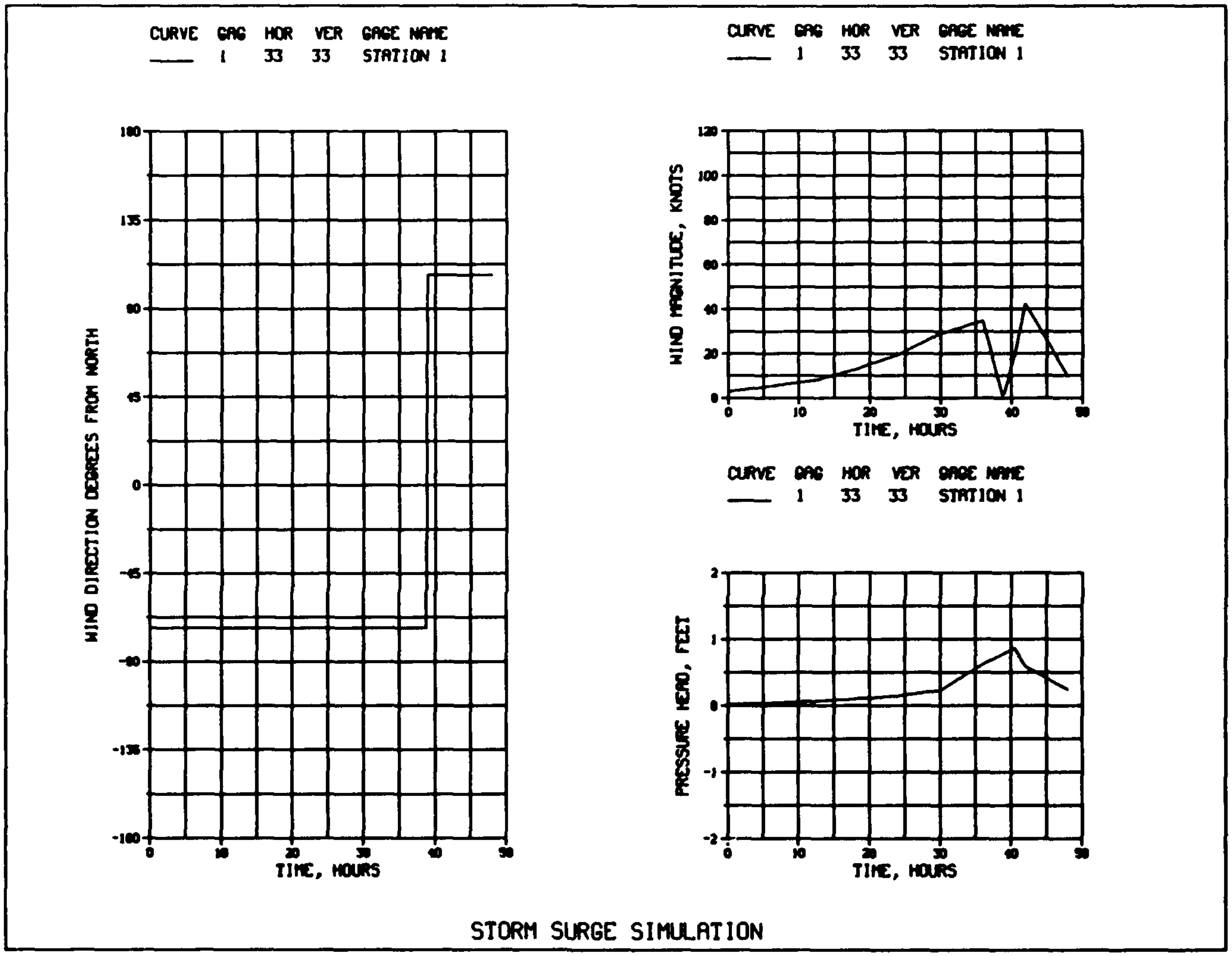


Figure 4-31. Wind and pressure at gage 1

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APPENDIX 4-A: WIFM DATA SPECIFICATION RECORDS

Model Control Specifications

(Req)	GENSPECS	Specify general title and system of units
(Req)	TIMESPEC	Specify time-related controlling variables
(Opt)	ADDTERMS	Specify optional terms in governing equations
(Opt)	STARTUP	Specify initial conditions

Grid Description

(Req)	GRIDSPEC	Specify general grid characteristics
(C-Opt)	XSTRETCH	Specify x-coordinates to create stretched grid
(C-Opt)	YSTRETCH	Specify y-coordinates to create stretched grid

Physical Characteristics

(Req)	BATHSPEC	Specify characteristics of bathymetry/topography
(Req)	--	Two-dimensional array of bathymetric/topographic data
(Opt)	CHNGBATH	Specify changes to the bathymetric/topographic data
(Opt)	FDRYSPEC	Change the flooding and drying defaults
(Opt)	XBARRIER	Specify barrier perpendicular to x-axis
(Opt)	YBARRIER	Specify barrier perpendicular to y-axis
(Opt)	BARRSPEC	Specify characteristics of barrier behavior
(Opt)	FRICTION	Specify character of bottom friction
(Opt)	FRICTABL	Specify entry for depth-variable friction table
(Opt)	CHNGFRIC	Modify the friction values at selected locations
(Opt)	TURNOFF	Remove portions of the grid from computations

Boundary Conditions

(Opt)	XBOUNDARY	Specify driving boundary perpendicular to x-axis
(Opt)	YBOUNDARY	Specify driving boundary perpendicular to y-axis
(C-Opt)	FUNCTION	Specify driving boundary forcing function
(C-Opt)	CNRECORD	Specify attributes of constituent forcing
(C-Opt)	CONSTIT	Specify harmonic constituent forcing function

(C-Opt)	TERECORD	Specify attributes of tabular elevation forcing

Boundary Conditions (Concluded)

(C-Opt)	TFRECORD	Specify attributes of tabular velocity forcing
(C-Opt)	TABELEV	Specify irregularly spaced tabular elevations
(C-Opt)	TABFLOW	Specify irregularly spaced tabular velocities

Wind Field Specifications

(Opt)	WINDSPEC	Specify the character of wind-field data
(C-Opt)	SPHSPEC	Specify general data for SPH wind-field model
(C-Opt)	TABSPH	Specify the SPH parameters at a given time
(C-Opt)	TABWINDS	Specify wind-field tabular data

Output Specifications

(Req)	PRWINDOW	Specify location and timing of a print window
(Opt)	RECGAGE	Specify location of recording gage in grid
(Opt)	RECSNAPS	Specify snapshot time(s) for recording
(Opt)	XRECRANG	Specify discharge range perpendicular to x-axis
(Opt)	YRECRANG	Specify discharge range perpendicular to y-axis

CMS Data Specification: GENSPECS Record: (Req)
Purpose: Specify general title and system of units.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		GENSPECS	Record identifier.
2-9	TITLE	Char *64	(Opt)		A*	General title for simulation.
10	SUNITS	Integer	(Opt)	ENGLISH	ENGLISH METRIC	Declares the system of units for model computations and results.

UNIT	ENGLISH (SI)	METRIC (British)
Length	ft	m
Time	sec	sec
Velocity	ft/sec	m/sec
Discharge	cu ft/sec	cu m/sec
Pressure	ft (of water)	m (of water)

CMS Data Specification: TIMESPEC Record: (Req)
Purpose: Specify time-related controlling variables.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		TIMESPEC	Record identifier.
2	DELT	Real	(Req)		+R*	Time-step for simulation (secs).
3	TUNITS	Char *8	(Opt)	HOURS	HOURS MINUTES SECONDS	Units for all time variables (except where noted).
4	TPROV	Real	(Opt)	0.	+R*	Provisional model time (in TUNITS) at start of simulation.
5	TMAX	Real	(Opt)	0.	+R*	Length of simulation (in TUNITS).
6	DTGAGS	Real	(Opt)	.25 hours	+R*	Time interval (in TUNITS) for recording time-history data (water velocities, free surface elevations, wind speeds, pressures).
7	DTHOTS (N/A to SPH)	Real	(Opt)	TMAX	+R*	Time interval (in TUNITS) for saving HOTSTART data.

CMS Data Specification: STARTUP Record: (Opt)
Purpose: Specify inital conditions.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		STARTUP	Record identifier.
2	SELEV	Real	(Opt)	0.	R*	Initial water surface elevation levels. Velocities are initialized to zero.
		(or) Char *8			HOTSTART	Field variables (m, u, and v) to be read (from file FNHOTI) to start simulation.
3	SECHO	Char *8	(Opt)	SHORT	SHORT	Short report of input and preliminary data to be written to file FNPRNT.
					DETAILED	Full (detailed) report of input and preliminary data to be written to file FNPRNT.
4-10	SNAME	Char *56	(Opt)		A*	Name of startup conditions.

CMS Data Specifiaction: ADDTERMS Record: (Opt)
Purpose: Specify optional terms in governing equations.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		ADDTERMS	Record identifier.
2	ADVTYP	Char *8	(Opt)	NOADVECT	NOADVECT	No advective (inertial) terms.
					NONCONS	Advective terms to be included in their "non-conservative" form.
					CONSERV	Advective terms to be included in their "conservative"form
3	DIFTYP	Char *8	(Opt)	NODIFFUS	NODIFFUS	No diffusion (eddy viscosity) terms.
					CONSTDIF	Diffusion terms to be included with a constant eddy viscosity coefficient: Ec
					VARDIF	Diffusion terms to be included with a variable "generalized" eddy viscosity coefficient: Eg
4	DIFCOF	Real	(C-opt)	0.	+R*	The eddy viscosity coefficient referenced above (required if CONSTDIF or *VARDIF specified for DIFFTYP*) - Ec for CONSTDIF - Eg for VARDIF
5	ADMASS	Real	(Opt)	0.	+R*	Constant rate at which water is added or removed (ex: rainfall, groundwater flows, evaporation) to the system (units are ft/TUNITS, or m/TUNITS ... as determined by SUNITS and TUNITS).

Notes:
(1) All terms on this record are omitted from the Governing Equations if this record is omitted.
(2) Wind terms are specified later as separate data (and are implicitly included if specified).

CMS Data Specification: GRIDSPEC Record: (Req)
Purpose: Specify general computational grid characteristics.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		GRIDSPEC	Record identifier.
2	GRTYPE	Char *8	(Opt)	RECTANG	RECTANG	Cartesian system with constant-spaced grid cells.
					RSTRETCH	Cartesian system with stretching function employed to create grid cells. (requires XSTRETCH and YSTRETCH records after the GRIDSPEC)
3	GUNITS	Char *8	(Opt)	ENGLISH	ENGLISH METRIC	System of units for grid data.
4	XCELLS	Integer	(Req)		+I*	Number of grid cells in x-direction.
5	YCELLS	Integer	(Req)		+I*	Number of grid cells in y-direction.
6	DX	Real	(Req)		+R*	Spatial stepsize in x-direction (in GUNITS).
7	DY	Real	(Req)		+R*	Spatial stepsize in y-direction (in GUNITS).
8	GLATT	Real	(Req)		R*	Latitude of grid origin (decimal degrees).
9	GLONG	Real	(Req)		R*	Longitude of grid origin (decimal degrees).
10	GALIGN	Real	(Req)		R*	Grid alignment: specified as angle of X-axis (for Cartesian systems) measured counter-clockwise from East (decimal degrees).

CMS Data Specification: XSTRETCH and YSTRETCH Records: (C-opt)
Purpose: Specify the data to create grid coordinates in a stretched rectilinear Cartesian coordinate system.

Field	Variable	Type	Status	Default	Permittted Data	Usage
1	CARDID	Char *8	(Req)		XSTRETCH YSTRETCH	Record identifier. (for X-coordinates) (for Y-coordinates)
2	ALPHAB	Integer	(Req)		I*	Alpha at beginning of grid subregion.
3	ALPHAE	Integer	(Req)		I*	Alpha at end of grid subregion.
4-5	A	Real	(Req)		R*	Stretching coefficients used to determine the X- and Y- coordinates in this grid subregion employing a power funtion of the form: X (or) Y = A + B * (ALPHA ** C)
6-7	B	Real	(Req)		R*	
8-9	C	Real	(Req)		R*	

Notes:
(1) Use one record per grid subregion (must be sequential..ie..Region1, Reqion2...etc.).
(2) These records may be generated by MAPIT in the CMSGRID package.
(3) These records are required if RSTRETCH was specified for GRTYPE on GRIDSPEC record.
(4) A, B, and C use a special format: each should be G16.9 (occupies two fields).

CMS Data Specification: TURNOFF Record: (Opt)
Purpose: Turn off (remove from computations) portions of grid.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		TURNOFF	Record identifier.
2	OFFX1	Integer	(Req)		+I*	Declares the location of the region to be turned off as a point, line or a rectangular area. OFFX1 is the minimum x-value, OFFY1 is the minimum y-value, OFFX2 is the maximum x-value, and OFFY2 is the maximum y-value.
3	OFFY1	Integer	(Req)		+I*	
4	OFFX2	Integer	(Opt)	0	+I*	
5	OFFY2	Integer	(Opt)	0	+I*	

CMS Data Specification: BATHSPEC Record: (Req)
Purpose: Specify general characteristics of the bathymetry/topography data.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		BATHSPEC	Record identifier.
2	BUNITS	Char *8	(Opt)	FEET	FEET METERS FATHOMS	Declares the units for the following bathymetry/topography data.
3	WDATUM	Real	(Opt)	0.	R*	Negative values of bathymetry (depths) are added to this datum value (in BUNITS).
4	LDATUM	Real	(Opt)	0.	R*	Positive values of topography are added to this datum (in BUNITS).
5	DLIMIT	Real	(Opt)	-6000. ft	R*	A limiting water depth (deeper values are set to this value in BUNITS).
6	BSEQ	Char *8	(Opt)	XY	XY -XY X-Y -X-Y YX -YX Y-X -Y-X	The 2-D array of bathymetry/topography which follows this record, is read in a sequence specified by this mnemonic code (see notes for the conventions represented by these mnemonics).
7-8	BFORM	Char *16	(Opt)	(8G10.3)	A*	Format used to read the following 2-D array of bathymetry/topography values.
9-10	BNAME	Char *16	(Opt)		A*	Name of bathymetry/topography set.

(Continued)

(Concluded)

Notes:

(1) The actual 2-D array of bathymetry/topography data follows this record.

(2) Conventions for 2-D array read sequence mnemonics:

```
****************** SEQ = XY ******************
      DO 1 J=1,YCELLS
1     READ(LUN,FORM) (VAR(I,J),I=1,XCELLS)

***************** SEQ = -XY ******************
      DO 2 J=1,YCELLS
2     READ(LUN,FORM) (VAR(I,J),I=XCELLS,1,-1)

***************** SEQ = X-Y ******************
      DO 3 J=YCELLS,1,-1
3     READ(LUN,FORM) (VAR(I,J),I=1,XCELLS)

***************** SEQ =-X-Y ******************
      DO 4 J=YCELLS,1,-1
4     READ(LUN,FORM) (VAR(I,J),I=XCELLS,1,-1)

****************** SEQ = YX ********************
      DO 5 I=1,XCELLS
5     READ(LUN,FORM) (VAR(I,J),J=1,YCELLS)

***************** SEQ = -YX ******************
      DO 6 I=1,XCELLS
6     READ(LUN,FORM) (VAR(I,J),J=YCELLS,1,-1)

***************** SEQ = Y-X ******************
      DO 7 I=XCELLS,1,-1
7     READ(LUN,FORM) (VAR(I,J),J=1,YCELLS)

**************** SEQ = -Y-X ******************
      DO 8 I=XCELLS,1,-1
8     READ(LUN,FORM) (VAR(I,J),J=YCELLS,1,-1)
```

CMS Data Specification: CHNGBATH Record: (Opt)
Purpose: Specify changes to the bathymetry data.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		CHNGBATH	Record identifier.
2	BATH	Real	(Req)		R*	New bathymetry/topography value (in BUNITS ... the two datum shift values LDATUM and WDATUM will not be applied to this value).
3	X1INDX	Integer	(Req)		I*	Declares the location of the bathymetry /topography value as a point, line, or a rectangular patch in the grid.
4	Y1INDX	Integer	(Req)		I*	
5	X2INDX	Integer	(Opt)	0	I*	
6	Y2INDX	Integer	(Opt)	0	I*	

Note:
(1) Use one CHNGBATH record per value (no changes if this record is omitted).
(2) All CHNGBATH records must follow two-dimensional bathymetry array.

CMS Data Specification: FDRYSPEC Record: (Opt)
Purpose: Change the flooding and drying defaults.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		FDRYSPEC	Record identifier.
2	ALLDRY	Real	(Opt)	30. ft 10. m	R*	The topography value designated as being always dry land (can never flood ... in SUNITS).
3	ALLWET	Real	(Opt)	-20. ft -6. m	R*	A bathymetry value that is a depth limit below which cells will never dry (always be wet ... in SUNINTS).
4	CEPSD	Real	(Opt)	0.2 ft 0.06 m	R*	Minimum depth of water defining a "dry cell" condition.
5	TIMCLS	Real	(Opt)	5 * DELT	R*	Hold a cell face closed for this minimum amount of time (in TUNITS) before opening.
6	TIMOPN	Real	(Opt)	5 * DELT	R*	Hold a cell face open for this minimum amount of time (in TUNITS) before closing.
7	CFWEIR	Real	(Opt)	4.0	R*	Weir coefficient for cell flooding and drying.
8	CDRAIN	Real	(Opt)	0.1	R*	Recession coefficient for cell flooding and drying.

Notes:
(1) Defaults apply if this record is omitted.
(2) A careful choice for ALLDRY and ALLWET values can significantly reduce the cost of a simulation.
(3) Other values should only be changed by experienced (or curious) users.

CMS Data Specification: FRICTION Record: (Opt)
Purpose: Specify character of bottom friction.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		FRICTION	Record identifier.
2	FRUNIT	Char *8	(Opt)	MANNING	MANNING CHEZY	Manning's "n" values given as data. Chezy coefficient given as data.
3	FRLAW	Char *8	(Opt)	QUADRAT	QUADRAT	Quadratic friction law used.
4	FRDEF	Char *8	(Opt)	CONSTANT	CONSTANT	Friction values constant in time and space; separate values for "land" and "water" areas permitted (see FRLAND and FRWATER below).
					VARYBATH	Friction values vary with bathymetry (as defined with FRICTABL records following this record).
5	FRLAND	Real	(C-opt)	.048 (SI) .040 (British)	+R*	Friction value for all "land" areas. (used only if CONSTANT specified for FRDEF).
6	FRWATR	Real	(C-opt)	.030 (SI) .025 (British)	+R*	Friction value for all "water" areas. (used only if CONSTANT specified for FRDEF).
7	FDMAX	Real	(Opt)	-300 ft -100 m	R*	Maximum water depth (in SUNITS) that will exert a change in variable friction.

Notes:
(1) If this record is omitted, the above default values will be used.
(2) If VARYBATH is selected for FRDEP, the table of friction values versus the depth follows this record as FRICTABL records.

CMS Data Specification: FRICTABL Record: (C-opt)
Purpose: Specify an entry in the friction value versus bathymetry table.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		FRICTABL	Record identifier.
2	FRICT	Real	(Req)		R*	Friction value (in FRUNITS).
3	FDEPTH	Real	(Req)		R*	Bathymetry value to use for the corresponding friction value (less than or equal to this depth)

Note: Friction values are not interpolated; they are assigned on a "less than or equal" basis governed by the given bathymetry value (in a range down to the next lower valued bathymetry entry); since the first entry (lowest bathymetry value) has no lower limit, all regions with bathymetry values less than this entry will have the friction value entry on the first FRICTABL record.

CMS Data Specification: CHNGFRIC Record: (Opt)
Purpose: Modify the friction values at selected locations.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		CHNGFRIC	Record identifier.
2	FRICT	Real	(Req)		+R*	New friction value (in FRUNIT).
3	X1INDX	Integer	(Req)		+I*	Declares the location of the new friction value as a point, line, or a rectangular patch of cells in the grid.
4	Y1INDX	Integer	(Req)		+I*	
5	X2INDX	Integer	(Opt)	0	+I*	
6	Y2INDX	Integer	(Opt)	0	+I*	

Notes:
(1) No changes to friction are made if this record is omitted.
(2) Use one CHNGFRIC record for each new friction value (or location).

CMS Data Specification: XBARRIER and YBARRIER Records: (Opt)
Purpose: Specify the location and characteristics of a subgrid-scale barrier.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		XBARRIER	Record identifier. (Aligned perpendicular to X- axis)
					YBARRIER	Record identifier. (Aligned perpendicular to Y- axis)
2	BRPOS1	Integer	(Req)		+I*	Cell indices declaring the barrier location within the grid; barrier extends from (and includes) cells BRPOS2 to BRPOS3 along the face of cell BRPOS1.
3	BRPOS2	Integer	(Req)		+I*	
4	BRPOS3	Integer	(Req)		+I*	
5	BARHT	Real	(Req)		R*	Elevation of the top of barrier (in SUNITS) relative to the datum.
6	BARMAN	Real	(Opt)	.025 (SI) .03 (British)	R*	Manning's "n" for flow over the barrier during a "submerged" state.
7	BARCOF	Real	(Opt)	2.7 (SI) 4.9 (British)	R*	Admittance coefficient for flow over the barrier during an "overtopped" state.
8-10	BARNAM	Char *24	(Opt)		A*	Barrier name.

Note:
(1) Use one XBARRIER or YBARRIER record per barrier.

CMS Data Specification: BARRSPEC Record: (Opt)
Purpose: Specify the general characteristics of barrier behavior.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		BARRSPEC	Record identifier.
2	BEPSD	Real	(Opt)	0.2 ft 0.06 m	R*	Minimum depth of water defining a submerged barrier.
3	TIMSUB	Real	(Opt)	5 * DELT	+R*	Hold "submerged" barriers in this state for this minimum time period (in TUNITS).
4	TIMOVT	Real	(Opt)	5 * DELT	+R*	Hold "overtopped" barriers in this state for this minimum time period (in TUNITS).

Notes:
(1) Default values are used if this record is omitted.
(2) These variables should only be changed by experienced users.

CMS Data Specification: XBOUNDRY and YBOUNDRY Record: (OPT)
Purpose: Specify location and character of a driving boundary.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		XBOUNDRY	Record identifier. (Boundary perpendicular to X-axis)
					YBOUNDRY	(Boundary perpendicular to Y-axis)
2	BNDTYP	CHAR *8	(Req)		CONSTELV	All cells of the driving boundary act in unison as a single elevation forcing function.
					INTRPELV	Driving boundary cells vary independently as interpolated from two elevation forcing functions applied at the ends of the boundary segment.
					CONSTDIS	All cells of the driving boundary act in unison as a single discharge forcing function.
					BAROMETR	Driving boundary cells vary independently as determined by the "inverted barometer" effect (from wind-field and pressure data).
					UNIFLUX	Boundary is specified as a "uniform flux" condition.
3	BNPOS1	Integer	(Req)		+I*	Cell indices declaring driving boundary location within the grid: boundary extends from (and includes) cells BNPOS2 to BNPOS3 along cell BNPOS1.
4	BNPOS2	Integer	(Req)		+I*	
5	BNPOS3	Integer	(Req)		+I*	

(Continued)

(Concluded)

6	BNDFN1	Integer	(C-opt)	+I*	Integer index of forcing function (tabular or harmonic constituent) for CONSTELV, INTRPELV or CONSTDIS type boundaries.
7	BNDFN2	Integer	(C-opt)	+I*	Integer index of 2nd forcing function used for interpolation on a INTRPELV type boundary.
8-10	BNDNAM	Char *24	(Opt)	A*	Boundary name.

Notes:

(1) An XBOUNDRY or YBOUNDRY record is required for each distinct driving boundary.

(2) For BNDTYP of CONSTELV or CONSTDIS, a function must be provided (the same fuction may be shared by several driving boundaries).

(3) For BNDTYP of INTERPELV, two functions must be provided (and again may be shared).

CMS Data Specification: FUNCTION Record: (C-opt)

Purpose: Specify index number and character of driving boundary forcing function.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		FUNCTION	Record identifier.
2	FUNNO	Integer	(Req)		+I*	Index number of Function.
3	FUNTYP	Char *8	(Req)		HARMCNST	Elevation forcing function to be generated using harmonic constituents (two groups of data must follow this record ... CNRECORD and CONSTIT(s)).
					TABELEVS	Elevations are provided in tabular form (two groups of data must follow this record ... TERECORD and TABELEV or 1-D array).
					TABFLOWS	Discharges are provided in tabular form (two groups of data must follow this record ... TFRECORD and TABFLOW or 1-D array).
4	FUNITS	Char *8	(Opt)	FEET	FEET METERS FPS MPS	Declares units for the given elevations or flows (function values).
5	FMULT	Real	(Opt)	1.0	R*	The function values are multiplied by this factor.
6	FDATUM	Real	(Opt)	0.0	R*	The function values are added to this "datum" quantity.

(Continued)

(Concluded)

7	FSHIFT	Real	(Opt)	0.	R*	The function values are shifted in time by this amount (in TUNITS). NOTE: + Shift forward in time - Shift backward in time
8	FEATHR	Real	(Opt)	0.	R*	The function is gradually spline fit from initial conditions (usually zero) to the given function value over the FEATHR period (in TUNITS).

CMS Data Specification: CNRECORD Record: (C-opt)
Purpose: Specify physical coordinates and timing of a constituent forcing function.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		CNRECORD	Record identifier.
2	RLONG	Real	(Opt)	0.	R*	Record longitude (in decimal degrees).
3	RYEAR	Real	(Req)		I*	Year at beginning of record.
4	RMONTH	Real	(Req)		I*	Month at beginning of record.
5	RDAY	Real	(Req)		I*	Day (of month) at beginning of record.
6	RHOUR	Real	(Req)		R*	Hour (of day) at beginning of record.
7-10	RNAME	Char *32	(Opt)		A*	Record name.

Notes:
(1) This record must follow a FUNCTION record if HARMCNST was specified as FUNTYP.
(2) This record must be followed by one or more CONSTIT records.

CMS Data Specification: CONSTIT Record: (C-opt)
Purpose: Specify and quantify a harmonic constituent for a boundary forcing function.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		CONSTIT	Record identifier.
2	CNAME	Char *8	(Req)		A*	Constituent name (see list of 37 available constituents in Table 4-5)
3	CAMP	Real	(Req)		+R*	Constituent amplitude (in FUNITS).
4	CEPOCH	Real	(Req)		R*	Constituent epoch (decimal degrees).

Notes:
(1) Use one CONSTIT record for each constituent to be included in the forcing function.

CMS Data Specification: TERECORD and TFRECORD Record: (C-opt)

Purpose: Specify general information for a tabular elevation (TERECORD) or tabular (TFRECORD) boundary forcing function.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		TERECORD	Record identifier for tabular elevations.
					TFRECORD	Record identifier for tabular flows.
2	RENT	Integer	(C-opt)		+I*	Number of entries in the tabular record.
3	RSTART	Integer	(C-opt)		+I*	Index number of an entry in the tabular record to be used as the start of the record.
4	RRINT	Real	(Req)		+R*	Time interval (in TUNITS) at which entries are recorded (applies to regularly spaced data to be provided in a 1-D array following this record).
					IRREGINT	Tabular data are provided at irregular intervals (times of individual entries will be specified on TABELEV or TABFLOW records following this record).
5-6	RFORM	Char *16	(Opt)	(8G10.3)	A*	Optional format specifier used for reading tabular data (applies to regularly spaced data provided in a 1-D array following this record ... does not apply if IRREGINT selected for RRINT above).
7-10	RNAME	Char *32	(Opt)		A*	Tabular record name.

Notes:
(1) This record must follow a FUNCTION record if TABELEVS or TABFLOWS specified for FUNTYP.
(2) If the tabular data are regularly spaced (in time), a 1-D array must follow this record.
(3) If the tabular data are provided at irregular time intervals, one or more TABELEV or TABFLOW records must follow this record.

CMS Data Specification: TABELEV or TABFLOW Records: (C-Opt)
Purpose: Specify the time and value of an entry in an irregularly spaced tabular elevation or flow forcing function.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		TABELEV	Record identifier for a tabular elevation entry.
					TABFLOW	Record identifier for a tabular flow entry.
2	FHR	Real	(Req)		R*	Hour of the tabular entry (hours).
3	FMIN	Real	(Req)		R*	Minute of the tabular entry (minutes).
4	FSEC	Real	(Req)		R*	Second of the tabular entry (seconds).
5	FMAG	Real	(Req)		R*	Value of tabular entry at the above time (in FUNITS).

Notes:
(1) Use one TABELEV or TABFLOW record for each entry of the tabular forcing function.

CMS Data Specification: WINDSPEC Record: (Opt)
Purpose: Specify the character of wind-field data.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		WINDSPEC	Record identifier.
2	WTYPE	Char *8	(Opt)		TABULAR SPH	Tabular wind data (follow this record). SPH wind-field model used in simulation.
3	WNTRVL	Char *8	(Opt)		CONSTANT	If WTYPE = TABULAR, winds are constant with respect to time and space. One TABWINDS record should follow this record. If WTYPE = SPH, this implies a constant translation storm. One TABSPH record should follow this record.
					VARIABLE	If WTYPE = TABULAR, winds are constant in space, but vary with time. Several TABWINDS records might follow this record. If WTYPE = SPH, this implies a variable translation storm. Several TABSPH records might follow this record.
4	WUNITS	Char *8	(Opt)	FPS	MPH FPS MPS KNOTS	Units for wind values.
5	PUNITS	Char *8	(Opt)	FEETH2O	MILLIBAR FEETH2O METERH2O PSI INCHESHG MMHG	Units for atmospheric pressure. (Feet of water) (Meters of water) (Pounds/square inch) (Inches of mercury) (millimeters of mercury)

(Continued)

(Concluded)

6	WINTRP	Real	(Opt)	0.	+R*	Time interval (in TUNITS) to interpolate wind field from given values.
7	WFETHR	Real	(Opt)	0.	+R*	The wind field is gradually spline fit from quiescent conditions to the given (or interpolated) value over the WFETHR period (in TUNITS).
8-10	WNAME	Char *24	(Opt)		A*	Wind event name.

Note: (1) No winds are applied to the model if this record is omitted.
(2) One SPHSPEC record is required when WTYPE = SPH.

CMS Data Specification: SPHSPEC Record: (C-opt)
Purpose: Specify general data to be employed by an SPH wind-field model.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		SPHSPEC	Record identifier.
2	PRFPRS	Real	(Req)		+R*	Atmospheric pressure at periphery of storm (in PUNITS).
3	RMAXE	Real	(Req)		+R*	Effective radius parameter (a form factor that adjusts the radial wind field distribution.
4	SPHDLT	Real	(C-opt)		R*	Time between calculated wind fields (applies to constant translation storms only .... in TUNITS).
5	HTRACK	Real	(C-opt)		R*	Direction of storm movement (applies to constant translation storms only ... in decimal degrees).
6	VTRANS	Real	(C-opt)		R*	Forward speed of storm (applies to constant translation storms only) in WUNITS.

CMS Data Specification: TABSPH Record: (C-opt)
Purpose: Specify the SPH parameters at a given time.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		TABSPH	Record identifier.
2	SPHOUR	Real	(Req)		R*	Hour at which these SPH parameters occur. (hours)
3	SPHMIN	Real	(Req)		R*	Minute at which these SPH parameters occur. (minutes)
4	SPHLAT	Real	(Req)		R*	For constant translation storms: Latitude of storm eye at landfall. For variable translation storms: Latitude of storm eye at above time denoted by SPHOUR AND SPHMIN. (decimal degrees)
5	SPHLNG	Real	(Req)		R*	For constant translation storms: Longitude of storm eye at landfall. For variable translation storms: Longitude of storm eye at above time denoted by SHPOUR AND SHPMIN. (decimal degrees)
6	CPI	Real	(Req)		+R*	Central pressure index (in PUNITS).
7	RMAX	Real	(Req)		+R*	Radius to maximum winds (nautical miles)
8	MAXWND	Real	(Req)		+R*	Maximum wind speed (in WUNITS).
9	AZMUTH	Real	(Req)		R*	Angle to maximum winds (decimal degrees).
10	NGRESS	Real	(Req)		R*	Wind inflow angle (decimal degrees).

Notes:
(1) At least one TABSPH record must follow an SPHSPEC record.
(2) Use one TABSPH record for each time entry to describe the variable translation storm.

CMS Data Specification: TABWINDS Record: (C-opt)
Purpose: Specify wind-field (spatially constant) tabular entry.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		TABWINDS	Record identifier.
2	WHR	Real	(Req)		R*	Hour of wind data entry (hours).
3	WMIN	Real	(Req)		R*	Minute of wind data entry (minutes).
4	WMAG	Real	(Req)		R*	Wind magnitude (in WUNITS) at above time.
5	WDIR	Real	(Req)		R*	Wind direction (decimal degrees) at above time.

Notes:
(1) Use one TABWINDS record to specify each entry in the tabular wind record.
(2) These records must follow the WINDSPEC record if TABULAR was specified for WTYPE.

CMS Data Specification: PRWINDOW Record: (Opt)
Purpose: Specify location and timing of a print window.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		PRWINDOW	Record identifier.
2	WXCEL1	Integer	(Opt)	1	+I*	Cell indices declaring the grid subregion or window for printing the selected variables. The window will be bounded by (and include) the region from (WXCEL1,WYCEL1) to (WXCEL2,WYCEL2).
3	WXCEL2	Integer	(Opt)	XCELLS	+I*	
4	WYCEL1	Integer	(Opt)	1	+I*	
5	WYCEL2	Integer	(Opt)	YCELLS	+I*	
6	WPRINT	Real	(Opt)	1.0 (HR)	+R*	Time interval (in TUNITS) at which the print window is to be recorded.
7	WPRSTR	Real	(Opt)	0.	+R*	Time (in TUNITS) at which print window is to begin recording.
8	WPREND	Real	(Opt)	TMAX	+R*	Time (in TUNITS) at which print window is to end recording.
9-10	WPRVAR	Char *16	(Opt)	EV	E	Water surface elevations.
					V	Water velocities (two components).
					W	Wind velocities (two components).
					B	Bathymetry value.
					D	Depth of water column.
					F	Friction value.
					T	E and V at previous time step (three values).
					S	Status flags.
					P	Atmospheric pressure

Note: Use 1 PRWINDOW record/window (in space or time).

CMS Data Specification: RECGAGE Record: (Opt)
Purpose: Specify location and character of a recording gage in the grid.

Field	Variable	Type	Status	Default	Permitted Data	
1	CARDID	Char *8	(Req)		RECGAGE	Record identifier.
2	GXPOS	Integer	(Req)		+I*	X-index of gage location within grid.
3	GYPOS	Integer	(Req)		+I*	Y-index of gage location within grid.
4	GTYPE	Char *8	(Opt)	UavgVavg	UavgVavg UavgV UVavg UV U V Uavg Vavg	Methods of computing the velocity recorded at this gage.
5-10	GNAME	Char *45	(Opt)		A*	Gage name.

Notes:
(1) Use 1 RECGAGE record per gage.
(2) The interval for recording all gage data was specified by DTGAGE on the TIMESPEC record.
(3) Variabler GTYPE is only applicable to averaging water velocities generated by WIFM and does does not affect output from model SPH.

CMS Data Specification: RECSNAPS Reocrd: (Opt)
Purpose: Specify snapshot time(s) for recording.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		RECSNAPS	Record identifier.
2	SNPTYP	Char *8	(Req)		INTERVAL	Snapshot data to be recorded at regular time intervals.
3	SNPINT	Real	(Opt)	1.0 (hr)	+R*	Regular time interval (in TUNITS) at which snapshot data are to be recorded. Changes to the default value must be in TUNITS.
4	SNPSTR	Real	(Opt)	0.	+R*	Time (in TUNITS) at which snapshot recording is to begin.
5	SNPEND	Real	(Opt)	TMAX	+R*	Time (in TUNITS) at which snapshot recording is to end.

------------------------- Alternate form for specific times -------------------------

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		RECSNAPS	Record identifier.
2	SNPTYP	Char *8	(Req)		TIMES	Snapshot data to be recorded at specific times (which follow on this record in fields 3-10).
3-10	SNPTIM	Real	(Req)		+R*	Time (in TUNITS) at which a snapshot is to be recorded (one SNPTIM/field in fields 3-10). Use additional records of this format if more than eight specific times are required.

Notes: (1) Any number of both types of snapshot records may be specified.
(2) Times specified must be integer multiples of DELT

CMS Data Specification: XRECRANG and YRECRANG Records: (Opt)
Purpose: Specify location and name of a discharge recording range within the grid.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		XRECRANG	Record identifier. (Range perpendicular to X-axis)
					YRECRANG	Record identifier. (Range perpendicular to Y-axis)
2	RPOS1	Integer	(Req)		+I*	Cell indices declaring recording range location within the grid: Range extends from (and includes) cells RPOS2 to RPOS3 along the face of cell RPOS1.
3	RPOS2	Integer	(Req)		+I*	
4	RPOS3	Integer	(Req)		+I*	
5-10	RRNAME	Char *45	(Opt)		A*	Range name.

Notes:
(1) Use 1 XRECRANG or YRECRANG record per range.
(2) The time interval for recording range data in file FNHIST was specified by DTGAGS on the TIMESPEC record.

CHAPTER 5

REGIONAL COASTAL PROCESSES WAVE PROPAGATION MODEL

THEORY AND PROGRAM DOCUMENTATION

PART I: INTRODUCTION

1. This chapter documents the Regional Coastal Processes Wave (RCPWAVE) Propagation Model. RCPWAVE is a short-wave numerical model used to predict linear, plane wave propagation over an open coast region of arbitrary bathymetry. The goal of regional modeling is to determine coastal changes resulting from natural forces and man-made structures over an extensive length of coastline. RCPWAVE uses linear wave theory because it has been shown to yield fairly accurate first-order solutions to wave propagation problems and at a relatively low cost. Refractive and bottom-induced diffractive effects are included in the model; however, the model cannot treat diffraction caused by surface-piercing structures. Application of this model does not include nonlinear effects nor a spectral representation of irregular waves.

2. RCPWAVE has evolved as it has been applied to wave propagation problems (Ebersole, Cialone, Prater 1986). The model results can be used as a forcing function to drive models that calculate longshore and cross-shore sediment transport (Hanson and Kraus 1989). For example, RCPWAVE has been used in conjunction with the shoreline change model, GENESIS, for mission support projects at Homer Spit, Alaska (Chu et al. 1987); Sea Bright to Ocean Township, New Jersey (Kraus et al. 1988); and Asbury Park to Manasquan, New Jersey (Gravens et al. 1989).

3. Berkhoff (1972, 1976) derived an elliptical equation to approximate the complete wave transformation process for linear waves over arbitrary bathymetry with the restriction of a mild bottom slope. By substituting the velocity potential into the elliptic mild slope equation and solving the real and imaginary parts separately, two equations are derived. RCPWAVE solves finite difference approximations of these equations along with the equation specifying irrotationality of the wave phase function gradient and the dispersion relation. These equations describe the combined refraction and diffraction process for linear plane waves subject to the restrictions of a small bottom slope. Wave reflections are assumed to be negligible, and any

energy losses are assumed to be small and can be neglected. These equations are valid outside the surf zone.

4. The model also contains an algorithm that estimates wave conditions inside the surf zone. This wave breaking model is an extension of the work of Dally, Dean, and Dalrymple (1984) to two horizontal dimensions. The importance of predicting wave transformation within the surf zone cannot be overemphasized. Wave action within the surf zone initiates sediment movement, and prediction of this movement is a frequent goal of coastal modelers.

5. This chapter is divided into five sections: Part II presents the theoretical development, Part III defines the input data formats, Part IV discusses the model's input data requirements, and Part V contains two illustrative examples.

PART II: THEORETICAL DEVELOPMENT

Assumptions and Limitations

6. Proper application of any model requires a clear understanding of the physical processes occurring in a study area and a comprehension of the capabilities of a given model to simulate those processes. Model results should provide a realistic representation of the physical system being modeled.

7. The limitations of a model define its range of applicability. In particular, RCPWAVE is a linear, monochromatic, short wave model. Therefore, nonlinear effects and irregular waves cannot be modeled. RCPWAVE is a steady-state model; therefore, time-dependent effects are not modeled. Refractive and bottom-induced diffractive effects are included in the model; however, structure-induced diffraction is not. Model applications are restricted to a mild bottom slope. Wave reflection and energy losses outside the surf zone are assumed negligible.

8. A thorough comprehension of the physical processes simulated by the model is necessary to ensure that the model is applied to appropriate problems, that it is applied correctly, and that accurate results are produced. A discussion of the governing equations used in RCPWAVE is provided in the following section. It is recommended that the reader refer to Horikawa (1988) or Dean and Dalrymple (1984) for a detailed discussion of coastal hydrodynamics, particularly linear wave propagation.

Governing Equations Outside the Surf Zone

9. Berkhoff (1972, 1976) derived an elliptical equation to approximate the complete wave transformation process for linear waves over an arbitrary bathymetry with the restriction of a mild bottom slope. Berkhoff's "mild slope" equation is:

$$\frac{\partial}{\partial x}\left(cc_g\frac{\partial\phi}{\partial x}\right) + \frac{\partial}{\partial y}\left(cc_g\frac{\partial\phi}{\partial y}\right) + \sigma^2\frac{c_g}{c}\phi = 0 \qquad (5\text{-}1)$$

where

x, y	=	two orthogonal horizontal coordinate directions
(x,y)	=	wave celerity $(= \sigma/k)$
σ	=	angular wave frequency (defined to be $2\pi/T$)
$k(x,y)$	=	wave number given by the dispersion relation $\sigma^2 = gk \tanh (kh)$
T	=	wave period
$c_g(x,y)$	=	group velocity $(\partial\sigma/\partial k)$
$\phi(x,y)$	=	complex velocity potential
g	=	acceleration due to gravity
$h(x,y)$	=	still-water depth

10. If one considers only the forward scattered wave field and neglects wave reflection, the velocity potential function for linear, monochromatic plane waves can be given as:

$$\phi = ae^{is} \tag{5-2}$$

where

$a(x,y)$	=	wave amplitude function $[gH(x,y)/2\sigma]$
$H(x,y)$	=	wave height
$s(x,y)$	=	wave phase function

11. By substituting Equation 5-2 into Equation 5-1 and solving the real and imaginary parts separately, two equations can be derived:

$$\frac{1}{a}\left\{\frac{\partial^2 a}{\partial x^2} + \frac{\partial^2 a}{\partial y^2} + \frac{1}{cc_g}\left[\nabla a \bullet \nabla(cc_g)\right]\right\} + k^2 - |\nabla s|^2 = 0 \tag{5-3}$$

$$\nabla \bullet (a^2 cc_g \nabla s) = 0 \tag{5-4}$$

where the symbol ∇ denotes the horizontal gradient operation. These equations describe the combined refractive-diffractive process.

12. Linear wave theory assumes irrotationality of the wave phase function gradient. This property can be expressed mathematically as:

$$\nabla x (\nabla s) = 0 \tag{5-5}$$

The phase function gradient, ∇s , can be written in vector notation as

$$\nabla s = |\nabla s| \cos\theta \, \vec{i} + |\nabla s| \sin\theta \, \vec{j} \tag{5-6}$$

where

$\vec{i}, \vec{j}$ = unit vectors in the x- and y-directions, respectively

$|\nabla s|$ = magnitude of the phase function gradient

θ = local wave direction

Equations 5-5 and 5-6 can be combined to yield the following expression:

$$\frac{\partial}{\partial x}(|\nabla s| \sin\theta) - \frac{\partial}{\partial y}(|\nabla s| \sin\theta) = 0 \tag{5-7}$$

If the magnitude of the wave phase function gradient is known, local wave angles can be calculated from Equation 5-7. Similarly, Equation 5-4 can be expressed as:

$$\frac{\partial}{\partial x}\left(a^2 c c_g |\nabla s| \cos\theta\right) + \frac{\partial}{\partial y}\left(a^2 c c_g |\nabla s| \sin\theta\right) = 0 \tag{5-8}$$

Equation 5-3 is solved for the magnitude of the wave phase function gradient, $|\nabla s|$; Equation 5-7 is solved for the wave angle, θ ; and Equation 5-8 is solved for the wave amplitude function, a . Equations 5-3, 5-7, and 5-8 along with the dispersion relation describe the combined refractive-diffractive process for linear plane wave propagation over a mild slope with negligible wave reflection and energy losses.

Numerical solution

13. Numerical methods are used to solve the three governing equations described previously. Analytical solutions of the governing equations may exist for idealized situations. However, it is generally necessary to use numerical approximations of the governing equations to provide a more general solution. This is accomplished by approximating the partial derivatives with finite difference operators (i.e. resolving the continuous domain of interest with discrete spatial increments). Finite difference solution methods operate on a computational grid system. Solution accuracy is directly related to resolution within the grid system.

14. The coordinate system convention adopted by RCPWAVE is oriented with the x-axis in the on-offshore direction and the y-axis alongshore (Figure 5-1). The grid cells have constant lengths of DX and DY in the x- and

y-directions, respectively. The cell counter in the x-direction, i , ranges from 1 to a maximum value of XCELLS. The cell counter in the y-direction, j , ranges from 1 to a maximum value of YCELLS.

15. As previously stated, the partial derivatives in the governing equations are approximated with finite difference operators. The first and second derivatives of an arbitrary dependent variable, say F, are approximated with the following finite difference operators:

$$\frac{\partial^2 F}{\partial x^2} = \frac{2F_{i,j} - 5F_{i+1,j} + 4F_{i+2,j} - F_{i+3,j}}{(\Delta x)^2} \tag{5-9}$$

$$\frac{\partial^2 F}{\partial y^2} = \frac{F_{i,j+1} - 2F_{i,j} + F_{i,j-1}}{(\Delta y)^2} \tag{5-10}$$

$$\frac{\partial F}{\partial x} = \frac{-3F_{i,j} + 4F_{i+1,j} - F_{i+2,j}}{2\Delta x} \tag{5-11}$$

$$\frac{\partial F}{\partial y} = \frac{F_{i,j+1} - F_{i,j-1}}{2\Delta y} \tag{5-12}$$

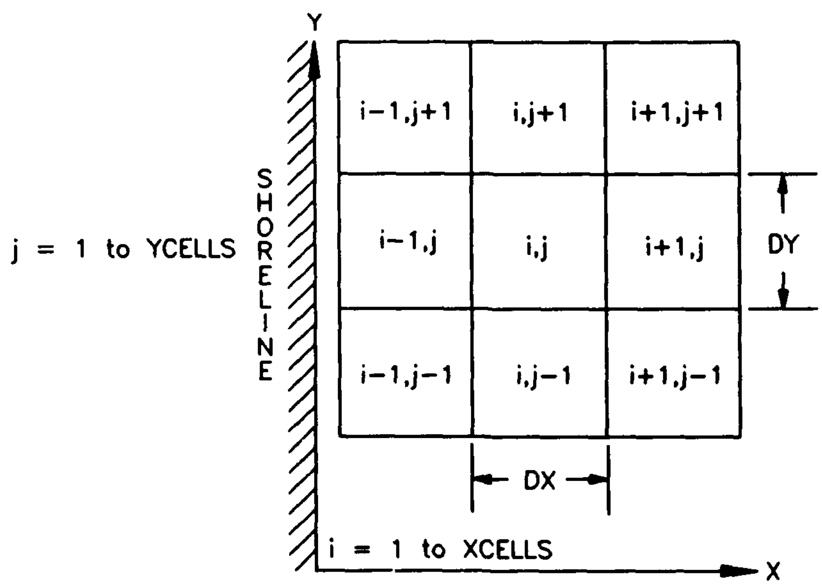

Figure 5-1. Definition of coordinate system and grid cell convention

16. Equations 5-10 and 5-12 are central differences, and Equations 5-9 and 5-11 are backward differences of the same order of accuracy. Backwards differences are used to approximate the derivatives in the x-direction because of the forward (-x-direction) marching scheme used in the model.

17. These difference equations can be used to approximate the partial derivatives in Equation 5-3:

$$|\nabla s|^2_{i,j} = k^2_{i,j} + \frac{1}{a_{i,j}}\left\{\left[\frac{2a_{i,j} - 5a_{i+1,j} + 4a_{i+2,j} - a_{i+3,j}}{(\Delta x)^2}\right]\right. \tag{5-13}$$

$$+ \left[\frac{a_{i,j+1} - 2a_{i,j} + a_{i,j-1}}{(\Delta y)^2}\right] + \frac{1}{cc_{g_{i,j}}}\left[\left(\frac{-3a_{i,j} + 4a_{i+1,j} - a_{i+2,j}}{2\Delta x}\right)\right.$$

$$\left.\left. * \left(\frac{-3cc_{g_{i,j}} + 4cc_{g_{i+1,j}} - cc_{g_{i+2,j}}}{(2\Delta x)}\right) + \left(\frac{a_{i,j+1} - a_{i,j-1}}{2\Delta y}\right)\left(\frac{cc_{g_{i,j+1}} - cc_{g_{i,j-1}}}{(2\Delta y)}\right)\right]\right\}$$

The remaining two governing equations, 5-7 and 5-8, have the general form:

$$\frac{\partial F}{\partial x} + \frac{\partial G}{\partial y} = 0 \tag{5-14}$$

The partial derivatives in equation 5-14 can be approximated using central differences about the point $(i-1/2,j)$. The final form of Equations 5-7 and 5-8 are:

$$\sin\theta_{i-1,j} = \frac{1}{|\nabla s|_{i-1,j}}\left[\left(\alpha|\nabla s|_{i,j+1}\sin\theta_{i,j+1} + (1-2\alpha)|\nabla s|_{i,j}\sin\theta_{i,j}\right.\right.$$

$$\left. + \alpha|\nabla s|_{i,j-1}\sin\theta_{i,j-1}\right) - \frac{W\Delta x}{2\Delta y}\left(|\nabla s|_{i-1,j+1}\cos\theta_{i-1,j+1}\right. \tag{5-15}$$

$$\left. - |\nabla s|_{i-1,j-1}\cos\theta_{i-1,j-1}\right) - \frac{(1-W)\Delta x}{2\Delta y}\left(|\nabla s|_{i,j+1}\cos\theta_{i,j+1}\right.$$

$$\left.\left. - |\nabla s|_{i,j-1}\cos\theta_{i,j-1}\right)\right]$$

and

$$a^2_{i-1,j} = \frac{1}{A_{i-1,j}}\Big[\left(\alpha a^2_{i,j+1} A_{i,j+1} + (1 - 2\alpha) a^2_{i,j} A_{i,j} + \alpha a^2_{i,j-1} A_{i,j-1}\right) \tag{5-16}$$

$$+ \frac{W\Delta x}{2\Delta y}\left(a^2_{i-1,j+1} B_{i-1,j+1} - a^2_{i-1,j-1} B_{i-1,j-1}\right) + \frac{(1 - W)\Delta x}{2\Delta y}\left(a^2_{i,j+1} B_{i,j+1} - a^2_{i,j-1} B_{i,j-1}\right) \Big]$$

where

A = $cc_g|\nabla s|\ \cos\theta$,

B = $cc_g|\nabla s|\ \sin\theta$,

W , α = weighting factors

The parameter W weights information between the known row, i , and the solution row, $i-1$. If W is 1.0, then an implicit solution of the equation is performed. If W is 0.0, then an explicit solution of the equation is performed. The weighting parameter α reflects use of a dissipative interface to enhance the stability of the numerical scheme (Abbott 1975).

Solution procedure

18. The following procedure is implemented in the model to solve finite difference Equations 5-13, 5-15, and 5-16:

a. Model input includes values of the deepwater wave height, H_o , direction, θ_o , and period, T , of the waves to be simulated along with bathymetric data for every grid cell.

b. The wave number, k , is computed using the dispersion relation and is used as an initial guess for the magnitude of the wave phase function gradient, $|\nabla s|$, at every grid cell.

c. The wave celerity, c , and the group velocity, c_g , are functions of the wave period and wave number and can, therefore, be calculated at each grid cell.

d. An estimate of the local wave angle, θ , can be calculated throughout the grid using this information and Snell's law,

$$\frac{\sin\theta}{c} = \frac{\sin\theta_o}{c_o} \tag{5-17}$$

where c_o is the deepwater wave celerity $(gT/2\pi)$. This estimate assumes that the bottom contours are parallel to the y-axis. If the bottom bathymetric contours make a known nonzero angle, θ_c , with the y-axis (Figure 5-2), a better first guess for the wave angles can be computed using the following approximation:

$$\theta = \pi - \sin^{-1}\left(\frac{\sin(\theta_o - \theta_c)}{\frac{C_o}{C}}\right) + \theta_c \tag{5-18}$$

e. Wave heights at each cell are estimated as the product of the deepwater wave height, H_0 , the shoaling coefficient, κ_s , and the refraction coefficient, κ_r , where

$$\kappa_s = \left[\frac{1}{\left(1 + \frac{2kh}{\sinh(2kh)}\right)\tanh(kh)}\right]^{1/2} \tag{5-19}$$

and

$$\kappa_r = \left(\frac{\cos(\theta_o - \theta_c)}{\cos(\theta - \theta_c)}\right)^{1/2} \tag{5-20}$$

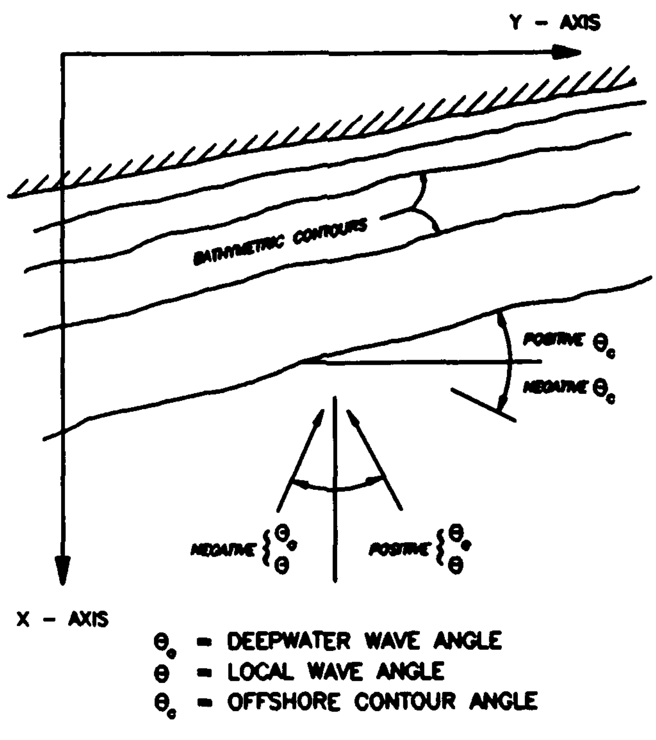

Figure 5-2. Definition of angle conventions used in the model

19. Following the determination of the initial guess for the variables of interest, a row-by-row marching scheme is implemented. Computations begin at the offshore row designated (i=XCELLS-3), where a solution for wave angles, heights, and numbers is determined for cells j=2 to j=YCELLS-1.

20. The implicit differencing formulation used in Equations 5-15 and 5-16 requires an iterative procedure to determine values of wave height and angle. Calculations are repeated until a convergence criterion is met. Convergence for wave height is achieved when the difference between the wave height computed from one iteration to the next iteration is less than a small value (0.0005 ft). Similarly, convergence for wave angle is achieved when the difference between the wave angle computed from one iteration to the next iteration is less than a small value (0.00025 rad). The third governing equation (5-13) is used to compute the wave phase gradient that accounts for the effects of diffraction.

21. Equations 5-15 and 5-16 are solved again with the new values of the wave phase function gradient. This procedure is repeated along the row under consideration until the phase functions satisfy a convergence criterion (i.e., the difference in the phase functions between consecutive iterations is less than 0.5 percent). This condition must be met at each cell along the row. Row by row marching proceeds until a solution is computed along row i=2.

Boundary conditions

22. Lateral boundary conditions for a row are specified upon completion of calculations for that row. The values of all variables at cells j=YCELLS and j=1 are set equal to the values at cells j=YCELLS-1 and j=2, respectively. This boundary condition implies that there is no change in wave properties in the y-direction. This condition is most valid when the grid y-axis parallels the bathymetric contours.

23. The seaward boundary condition (deepwater wave parameters) are used to initiate the shoreward marching procedure. Values along the seaward boundary are computed from deepwater wave input, assuming Snell's law is valid (i.e., the bottom contours are straight and parallel from the grid boundary to deep water). No inshore boundary condition (row $i = 1$) is necessary because of the forward marching scheme implemented in the model.

Wave transformation inside the surf zone

24. Since linear wave theory does not allow for the prediction of the breaker location nor for wave transformation across the surf zone, empirical and approximate methods must be used to describe incipient wave breaking and the subsequent decay of energy. Many empirical methods give reasonable approximations of incipient breaking wave height. RCPWAVE uses Weggel's (1972) criterion, which was developed by fitting an empirical relationship to field data on breaking waves:

$$H_b = \frac{\bar{b} h_b}{1 + \frac{\bar{a} h_b}{gT^2}} \tag{5-21}$$

where

$\bar{a}$ = $43.75 \left[1 - e^{(-19m)} \right]$

$\bar{b}$ = $1.56 / \left[1 + e^{(-19.5m)} \right]$

m = bottom slope

H_b = breaking wave height

h_b = water depth at breaking

25. After defining the incipient breaking point, a means of transforming the waves across the surf zone is needed. Dally, Dean, and Dalrymple (1984) developed an algorithm to approximate energy loss across the entire surf zone based on energy loss in a hydraulic jump.

$$\frac{\partial (Ec_g)}{\partial x} = \frac{-\kappa}{h} \left[Ec_g - (Ec_g)_s \right] \tag{5-22}$$

where

κ = energy dissipation coefficient (set to 0.2 in RCPWAVE)

(Ec_g) = energy flux associated with a breaking wave

$(Ec_g)_s$ = stable level of energy flux that the transformation process seeks to attain

The right-hand side of Equation 5-22 is simply a dissipative term. Substituting the linear wave theory estimate for E ($E = 1/8\ \rho g H^2$) into Equation 5-22 results in the following expression:

$$\frac{\partial(H^2 c_g)}{\partial x} = \frac{-\kappa}{h}\left[H^2 c_g - (H^2 c_g)_s\right] = D \tag{5-23}$$

26. It has been observed in field (Thornton and Guza 1982) and laboratory (Horikawa and Kuo 1966) experiments that, well into the surf zone, the wave height tends toward a stable value that is proportional to the local water depth:

$$H_s = \gamma h \tag{5-24}$$

where

H_s = stable wave height

γ = proportionality coefficient (set equal to 0.4 in RCPWAVE)

Equation 5-23 can now be written as

$$\frac{\partial(H^2 c_g)}{\partial x} = \frac{-\kappa}{h}\left[H^2 c_g - (\gamma^2 h^2 c_g)_s\right] = D \tag{5-25}$$

27. This surf zone wave transformation model can be incorporated into the conservation of wave energy equation (Equation 5-4) by simply adding the dissipation term D to the right-hand side. The function D must now represent dissipation in the direction of wave propagation. Also for dimensional consistency, the term D must be multiplied by the wave celerity and the magnitude of the wave phase gradient, and the wave height must be replaced by the wave amplitude function. In vector notation, the energy equation becomes

$$\nabla \bullet (a^2 c c_g \nabla s) = \frac{-\kappa}{h}\left\{a^2 c c_g |\nabla s| - \left[\left(\frac{g}{2\sigma}\right)^2 \gamma^2 h^2 c c_g |\nabla s|\right]_s\right\} \tag{5-26}$$

This equation can be thought of as being valid both inside and outside the surf zone. Outside, the coefficient κ is zero, and the equation reduces to Equation 5-4.

28. Discussion relating to wave transformation within the surf zone has addressed the problem of determining wave heights. The problem of wave phase must also be addressed. Diffractive effects are assumed to be negligible inside the surf zone. Therefore, the wave number, k , is assumed to accurately represent the wave phase function gradient in the surf zone.

29. Lastly, the linear wave theory assumption of irrotationality also will be assumed to remain valid inside the surf zone. Consequently, wave angles inside the surf zone are computed in the same manner that is used outside the surf zone.

Numerical solution

30. The numerical procedure for computing wave angles inside and outside the surf zone is the same. This section documents the solution scheme used to determine breaking wave heights. The finite difference form of the wave energy equation outside the surf zone (Equation 5-16) can be expressed in the following form:

$$a_{i-1,j}^2 = \frac{\bar{F} + \Delta x \bar{G}}{A_{i-1,j}} \tag{5-27}$$

where

$$\bar{F} = \alpha a_{i,j+1}^2 A_{i,j+1} + (1 - 2\alpha) a_{i,j}^2 A_{i,j} + \alpha a_{i,j-1}^2 A_{i,j-1} ,$$

$$\bar{G} = (1 - W)\left(\frac{a_{i,j+1}^2 B_{i,j+1} - a_{i,j-1}^2 B_{i,j-1}}{2\Delta y}\right),$$

$$B = cc_g |\nabla s| \sin\theta , \text{ and}$$

$$A = cc_g |\nabla s| \cos\theta .$$

With the inclusion of the dissipative term, Equation 5-27 becomes

$$a_{i-1,j}^2 = \frac{\bar{F} + \Delta x \bar{G}}{A_{i-1,j}} + \frac{\Delta x D^*}{A_{i-1,j}} \tag{5-28}$$

where D^* represents the finite difference form of the dissipation term on the right-hand of Equation 5-26. Reiterating, the dissipation term represents an average value along the wave path (direction of propagation). The wave path is determined by the local wave angle at the position *i-1,j* which has already been computed. Therefore, the average along the path is an average of information at cell *i-1,j* and another cell whose position is denoted by *ikey,jkey*. The procedure used for determining the location of this cell will be presented later.

31. The term D can be written in finite difference form as

$$D^{*} = \frac{k}{\bar{h}}\left\{\left[\frac{(a^2cc_g|\nabla s|)_{ikey,jkey} + (a^2cc_g|\nabla s|)_{i-1,j}}{2}\right]\right. \tag{5-29}$$

$$\left. - \left(\frac{g}{2\sigma}\right)^2\left(\frac{\gamma^2h^2cc_g|\nabla s|_{ikey,jkey} + \gamma^2h^2cc_g|\nabla s|_{i-1,j}}{2}\right)\right\}$$

where

$$\bar{h} = \frac{h_{i-1,j} + h_{ikey,jkey}}{2}$$

With some algebra, Equation 5-28 can be reorganized so that the amplitude function at the position $i-1,j$ appears only on the left-hand side of the equation. Therefore, the energy equation inside the surf zone can be numerically solved using the same procedure used to solve it outside the surf zone.

32. The location of the cell denoted *ikey,jkey* is found using the following procedure. "Areas of influence" are determined by extending lines from the center of the cell $i-1,j$ to the midpoints between the surrounding cell centers (Figure 5-3). Angles are computed from the x-axis to these radial lines. The local wave angle calculated at cell $i-1,j$ is compared with each of these angles in order to determine the nearest, prior cell (in row i) along the wave path. For example (refer to Figure 5-3), if the local wave angle is greater than θ_2 but less than θ_1, then cell $i,j+1$ is the cell of influence and $ikey = i$ and $jkey = j+1$.

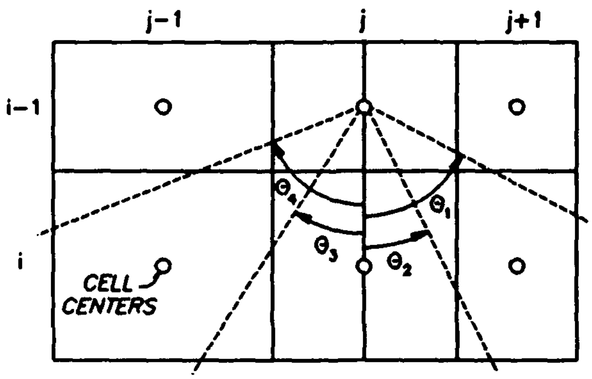

Figure 5-3. Cells of influence used in wave breaking scheme

33. A flowchart describing the wave height computation is shown in Figure 5-4. The wave amplitude function is computed from the energy equation assuming no dissipation. The amplitude function is converted to wave height and compared with the stable wave height γh. If the wave is less than or equal to this stable level, the wave has broken and attained a stable height, or it is outside the surf zone and unbroken. In either case, no consideration of dissipation is needed. If the wave height is greater than γh, the cell of influence is located and tested to determine whether or not the wave is breaking. If the wave is breaking in the cell of influence, it continues to decay in height. If the wave in the cell of influence is not breaking, the local wave height is checked against the incipient breaking height criterion. If the height exceeds the allowable value, wave dissipation begins. The accuracy of the surf zone wave transformation model has been verified using laboratory data of Horikawa and Kuo (1966) and Izumiya (1984). Results of the comparisons can be found in Ebersole, Cialone, and Prater (1986).

Computational stability

34. In applying RCPWAVE, it has been determined that the aspect ratio, $\Delta y/\Delta x$, plays an important role in determining the computational stability of the numerical solution scheme. The maximum allowable local wave angle is defined as the inverse tangent of the ratio $\Delta y/\Delta x$. Therefore, larger wave angles can be resolved by the model as this ratio increases (Figure 5-5).

35. Computational instability occurs when no energy reaches a cell in the computational domain, implying a zero wave height. This instability may occur when a cell (i,j) passes energy to cell $(i-1,j+1)$ while cell $(i,j-1)$ passes energy to cell $(i-1,j+1)$ (Figure 5-6a). Cell $(i-1,j)$ receives no energy and therefore is assigned a zero wave height. The diffractive portion of the model cannot recover from this situation. For irregular bathymetry, stability problems can occur when large bathymetry gradients cause strong wave refraction and local wave angles become large. Strongly oblique wave incidence is not a problem for plane beach simulations because every cell, j=1 to j=*YCELLS*, in a given row, i, behaves identically; therefore, energy is uniformly passed to every cell in row i-1 (Figure 5-6b).

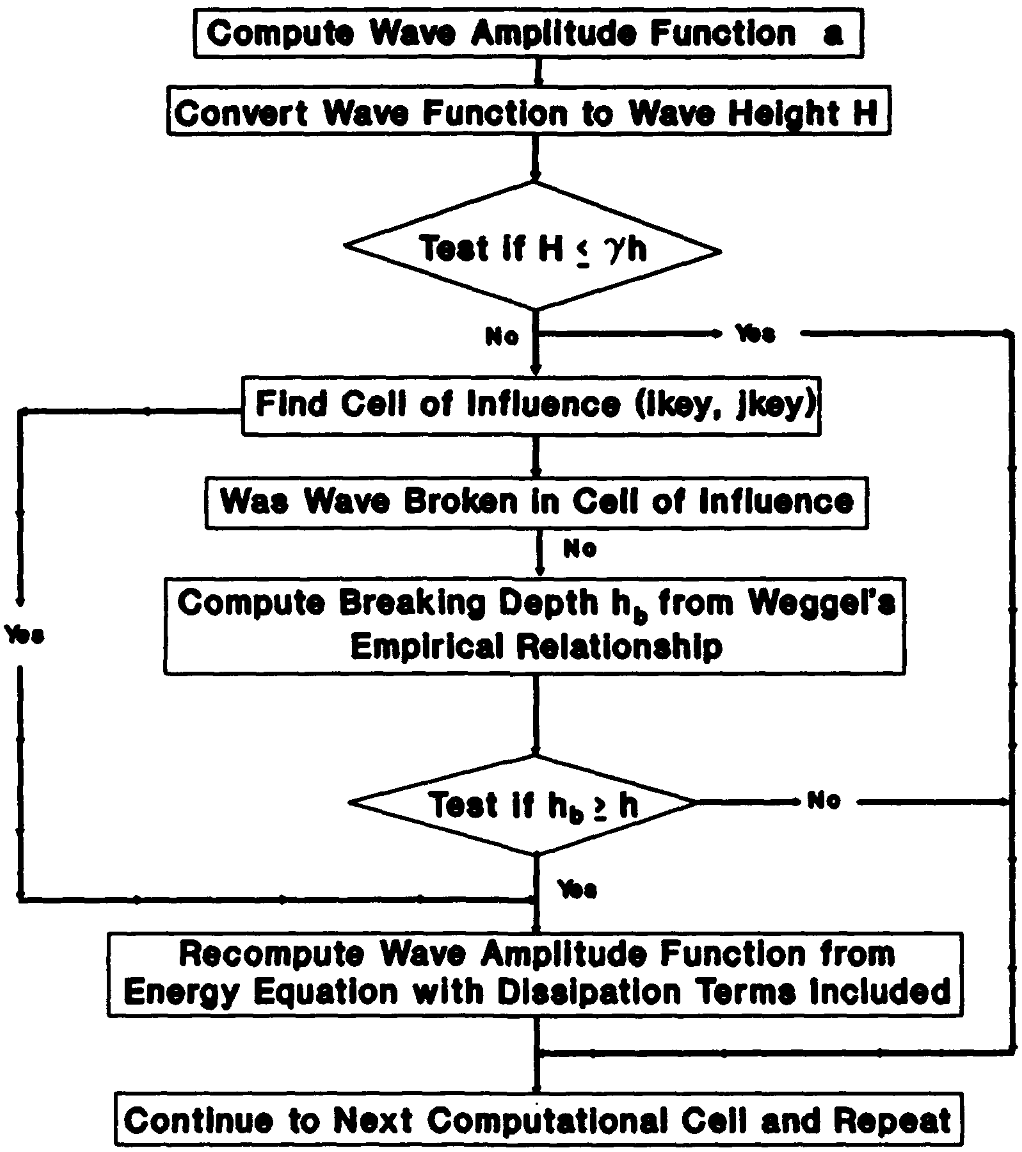

Figure 5-4. Flowchart of the wave breaking scheme

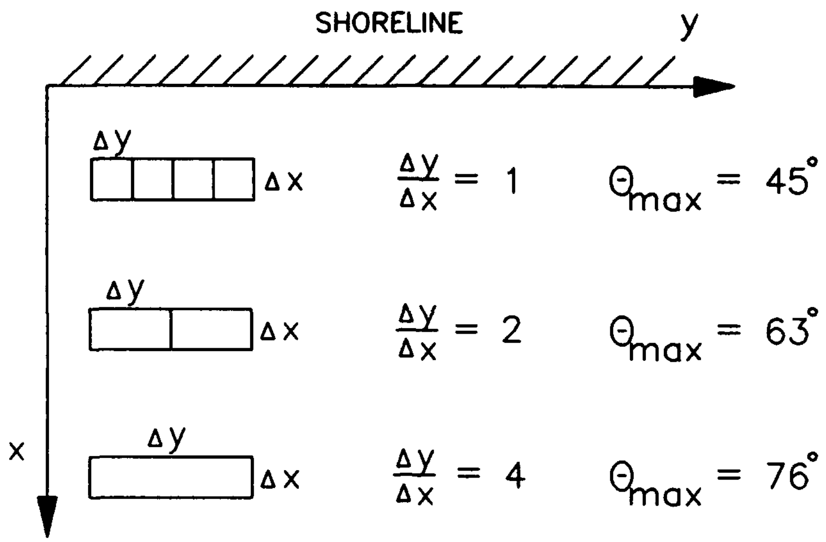

Figure 5-5. Aspect ratios and maximum allowable local wave angles

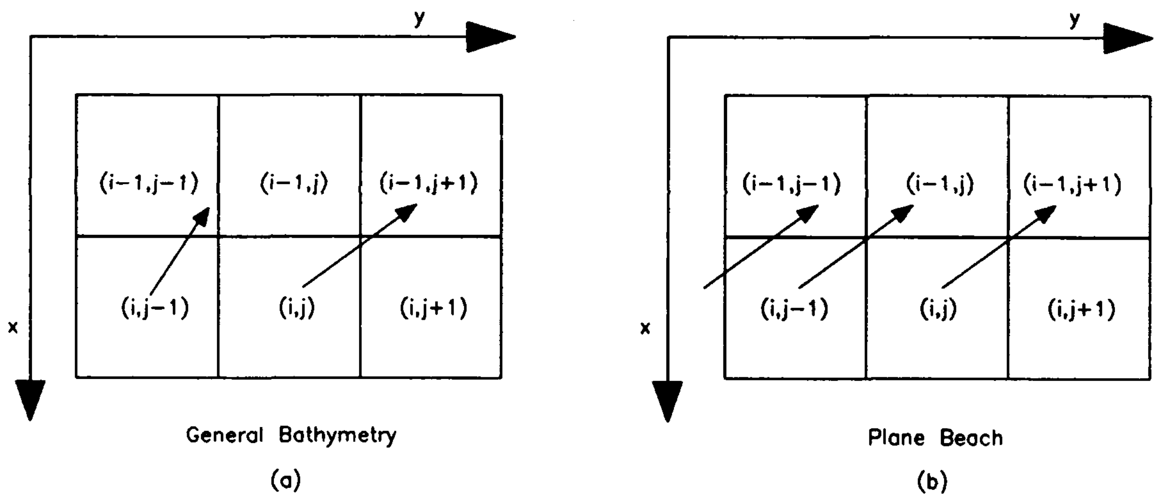

Figure 5-6. Schematic of wave energy passing from row *i* to row *i-1*

PART III: DEFINITION OF INPUT DATA FORMAT

36. The input data set format was designed to resemble the format required by the series of models released by the USAE Hydrologic Engineering Center. It is the intent that this structure, being familiar to Corps personnel, will reduce the time needed to learn this system. The general format of the input data set records, where a record refers to one line of data, is presented below:

- a. Each record is divided into 10 fields containing 8 columns each.
- b. Field 1, columns 1 through 8, contains a mnemonic identification label that describes the purpose or function of each record.
- c. Fields 2 through 10 contain data that may be real, integer, or character in type. Integers must be right justified. Real numbers must also be right-justified if the decimal point is omitted. Character data does not need to be right- or left-justified.
- d. Array data, such as depths, are read with DO or Implied DO loops. No label is required for each record containing array data. However, a general specification record, such as BATHSPEC which defines bathymetric attributes, must precede that array.

37. Spelling of record identification labels and alphanumeric variables is important. Misspelled entries will result in either recognized error conditions that force the model to abort execution, or bypassing of desired user-defined operations, such as bathymetric changes.

38. Certain records and variables have been assigned default values in the model for minimizing input data and computer resources. Thus, not all input data records will be needed for each application, and only those records pertinent to the simulation or required by the model should be included. Default values are representative of those chosen in previous studies performed by Coastal Engineering Research Center (CERC) staff. Although these quantities may not be applicable to all studies, they can serve as a guide when selecting replacement values.

39. Default values are processed when the record field corresponding to that variable is blank. Hence, the user must be careful when leaving fields blank in a record; blank fields will not necessarily result in a variable

being assigned a value of zero. These variables and their respective default values are noted in Appendix 5-A. The following discussion pertains to the general format of the input records given in Appendix 5-A.

40. Each record is presented in a standardized tabular format and has as its heading the mnemonic identification label or name with a brief description of its function. Following its name, the record has an abbreviated note documenting whether it is required for a simulation. These abbreviations have the following definitions:

(Req)	Record or variable is required for each simulation.
(Opt)	Record or variable is optional. Omitting this item results in either the default value being used or the defined operation not being performed.

For example, record BATHSPEC, presented in Appendix 5-A, contains the note (Req) meaning that this record must reside in the input data set for each simulation. Record CHNGBATH contains the note (Opt) meaning this record is optional and is only used when changes to the bathymetric data are desired.

41. Input variables, presented in column 2 of each table, are referenced to their respective record fields shown in column 1. Generally, data for each variable occupy a single 8-column data field. However, variables assigned titling or formatting information can occupy several fields.

42. Variable attributes are presented in columns 3 through 6 of each table. Valid data types are listed in column 3 and can be real, integer, or alphanumeric. Abbreviations presented in this column are described below:

Char*16	Alphanumeric character string containing up to 16 characters
Char*8	Alphanumeric character string containing up to 8 characters
Integer	Integer data
Real	Real (floating point) data

43. Column 4 of each table defines whether the respective variable must be assigned a value. Abbreviations listed in this column have identical meanings as those for the records. Default values are listed in column 5. A blank entry in this column denotes that the respective variable is not assigned a default value.

44. Column 6 of each table lists the variables' permitted data type or all valid character strings. Variables having integer or real data types are specified with the following notation:

A	Alphanumeric values
+R	Positive real values
R	Positive, zero, or negative real values
+I	Positive integer values
I	Positive, zero, or negative integer values

45. Variable definitions are listed in table column 7 of each table. Variables whose quantities are unit-dependent contain a reference to that variable designating its system of units. For example, variable WDATUM is assigned a value having units defined by variable BUNITS. Variables defining input data units and the record on which they reside are presented below.

Variable	Record	Definition
BUNITS	BATHSPEC	bathymetry/topography data
GUNITS	GRIDSPEC	numerical grid data
SUNITS	GENSPECS	model computations and output

Part IV: DISCUSSION OF THE INPUT DATA REQUIREMENTS

46. The types of data processed by RCPWAVE are not extremely extensive. However, since each application is unique, the type of input data required for each study will vary. In this discussion of model input, data have been divided into four categories to present model capabilities and data requirements. These categories are:

- a. Model control specifications.
- b. Grid description.
- c. Physical characteristics.
- d. Output specifications.

47. Table 5-1 presents RCPWAVE input data records pertaining to each category. A record refers to one line of data, and each record begins with a mnemonic character string to identify one record type from another. Record format and detailed specification for each record are presented in this chapter. While reading Part IV, the user will find it beneficial to refer to Appendix 5-A.

Model Control Parameters

48. The only data record contained in this category is the GENSPECS record. Record GENSPECS is used to specify the general title of the simulation (TITLE) and the system of units (SUNITS) used for model computations and displaying model results. Variable names are given in parentheses. Additional titles may be selected for specific input data records. Although this information is optional, it can be very helpful when reviewing a series of simulations. A title should specifically state data attributes, such as data source or collection date, to differentiate from data used in other simulations.

49. Model output is displayed in either English or metric units. However, the user can specify a different system of units for the input data. For example, the user can supply bathymetry data having units of feet or meters. RCPWAVE will convert the input data into the necessary system of units.

Table 5-1

Input Data Set Records

Category	Record Name
Model control specifications	GENSPECS
Grid description	GRIDSPEC
Physical characteristics	BATHSPEC CHNGBATH WAVCOND CONVERG
Output specifications	PRWINDOW PLOTREC

Grid Description

50. The study area is defined in the model via a computational grid. The grid is composed of rectilinear cells, where each cell is assigned a two-dimensional index. The first index, i , corresponds to the x-coordinate, and the second index, j , corresponds to the y-coordinate. The grid index system was presented in Figure 5-1. All wave data, such as wave heights, are assigned and referenced to their respective grid cells with this system. Guidelines for developing grids are discussed in Appendix A of the *CMS User's Manual*.

51. Selection of a grid coordinate system is controlled by variable GRTYPE on record GRIDSPEC. RCPWAVE permits a rectilinear uniform grid coordinate system only. A uniform, or constant grid cell size is selected by assigning the character string RECTANG to variable GRTYPE.

52. Variable GUNITS on record GRIDSPEC controls the system of units for the computational grid. Valid units are feet and meters. RCPWAVE will convert the data to the system of units for computations (SUNITS) internally. Variables XCELLS and YCELLS specify the number of grid cells in the x- and y-directions, respectively. Variables DX and DY on record GRIDSPEC specify the grid's cell size in the x- and y-directions, respectively.

Topography/bathymetry

53. Each grid cell must be assigned a water depth or land elevation. Topography/bathymetry data are referenced relative to an arbitrary datum. Typically, the map datum from which the depths are taken is used. Water cells are designated by negative values, whereas land cells have positive values.

54. One BATHSPEC record is required for defining the general characteristics of the topography/bathymetry array and must precede this array. Variable BUNITS defines the units of topography/bathymetry data. Valid units are feet, meters, or fathoms. The input sequence for reading this array is controlled by variable BSEQ. Eight options for the input sequence are available for reading the array data and are documented in Table 5-2. As an example, for the first input sequence (Figure 5-7), the depths are read along the x-direction, then y is incremented to a value of 2, and again the sweep in the x-direction takes place. This procedure is repeated until the entire array is read. The input format for reading this array can be selected by the user with variable BFORM.

55. The maximum water depth is specified with variable DLIMIT and any array values deeper than DLIMIT are set to DLIMIT (in BUNITS). Grid-wide adjustments to land elevations contained in the topography/bathymetry array can be made with variable LDATUM. The value assigned to this variable is added to all land cells in the grid. Positive LDATUM values will increase land elevations, whereas negative values will decrease land elevations. Similarly, grid-wide adjustments to water depths can be made with variable WDATUM. The value assigned to this variable is added to all water cells. Since these cells have negative values, positive WDATUM values produce shallower depths.

56. Changes to the topography/bathymetry array can also be made to individual cells or a group of cells with record CHNGBATH. This record allows the user to quickly change values assigned to the bathymetry array (using variable BATH) without editing the array itself. It should be noted that (a) values of the variable BATH on the CHNGBATH record are assumed to have units consistent with those selected for bathymetry/topography (i.e., variable BUNITS on record BATHSPEC), and (b) LDATUM and WDATUM are not applied

Table 5-2

Input Sequence for Array Data

No	Sequence	Description
1	XY	DO 1 J=1,YCELLS 1 READ(LUN,FORM) (VAR(I,J),I=1,XCELLS)
2	-XY	DO 2 J=1,YCELLS 2 READ(LUN,FORM) (VAR(I,J),I=XCELLS,1,-1)
3	X-Y	DO 3 J=YCELLS,1,-1 3 READ(LUN,FORM) (VAR(I,J),I=1,XCELLS)
4	-X-Y	DO 4 J=YCELLS,1,-1 4 READ(LUN,FORM) (VAR(I,J),I=XCELLS,1,-1)
5	YX	DO 5 I=1,XCELLS 5 READ(LUN,FORM) (VAR(I,J),J=1,YCELLS)
6	-YX	DO 6 I=1,XCELLS 6 READ(LUN,FORM) (VAR(I,J),J=YCELLS,1,-1)
7	Y-X	DO 7 I=XCELLS,1,-1 7 READ(LUN,FORM) (VAR(I,J),J=1,YCELLS)
8	-Y-X	DO 8 I=XCELLS,1,-1 8 READ(LUN,FORM) (VAR(I,J),J=YCELLS,1,-1)

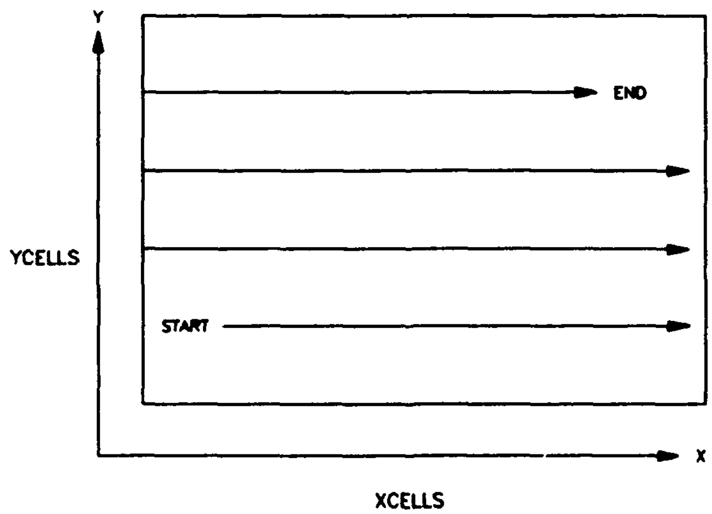

Figure 5-7. Input sequence - option 1

to cells specified with record CHNGBATH; therefore, the effect of nonzero LDATUM and WDATUM must be included in the value of variable BATH.

57. Variables X1INDX and X2INDX on the CHNGBATH record specify the minimum and maximum cell numbers in the x-direction, respectively, where the topography/bathymetry value will change. Similarly, variables Y1INDX and Y2INDX on the CHNGBATH record specify the minimum and maximum cell numbers in the y-direction, respectively, where the topography/bathymetry value will change. More than one CHNGBATH record is permitted.

Wave conditions

58. Each simulation requires wave information in deep water (i.e., the deepwater wave height, direction, and period). The angle which the offshore contour makes with the grid y-axis is also needed (see Figure 5-4 for the angle definition/sign convention).

59. A WAVCOND record is required to define each of the deepwater wave conditions to be simulated. One WAVCOND record is required for each wave condition to be simulated, and multiple wave conditions are permitted for a single simulation. Simulations are usually limited, however, to 5 to 10 wave conditions grouped together in a logical manner. Diffractive effects can be included or excluded for any given simulation by specification on the WAVCOND record.

60. Variables HDEEP, TDEEP, and ZDEEP specify the deepwater wave height, period, and deepwater wave angle, respectively. Variable CNTRNG is used to define the offshore contour angle. The inclusion of topography-induced diffractive effects is accomplished by setting DIFFR equal to YES.

Convergence criteria

61. Certain model parameters can be modified to alter how quickly the model converges toward a solution to the governing equations. When the change in a given variable from iteration to iteration is less than a specified value, the model has "converged" on a solution. The change in the variable from iteration to iteration is called the convergence criterion. Variables HCONVR and SCONVR on record CONVERG are convergence criteria for wave heights and wave angles, respectively. ITAMX and IDIFF are the maximum number of iterations for wave heights/angles and diffraction computations, respectively. Default values for the convergence criteria have been developed based on experience. Users should not change these values arbitrarily.

62. Certain model parameters are used to specify the stable wave height and rate of wave height decay through the surf zone. Variables STABL and DECAY on record CONVERG are used to set the stability and decay coefficients used in surf zone computations. For more information on the selection of these values, refer to Dally, Dean, and Dalrymple (1984).

Output Specifications

63. RCPWAVE generates an output listing containing a summary of the input data set for every simulation. Error and warning diagnostic messages are also contained in this listing. A sample output listing containing a summary of the input dataset is presented in Figure 5-8.

```
         ---              PLANE BEACH EXAMPLE                          ---

***** FILES CARD:  SPECIFICATION OF PERMANENT FILE NAMES FOR DATA STORAGE/RETRIEVAL

VARIABLE  DESCRIPTION OF USAGE:              VALUE:    NOTES:  * VARIABLE  DESCRIPTION OF USAGE:                VALUE:   NOTES:
--------  ---------------------------------  --------  ------- * --------  -----------------------------------  -------  -------
FNPRNT    FILE FOR PRINTED OUTPUT            CMSPRNT           *

***** GENSPECS CARD:  SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE  DESCRIPTION OF USAGE:              VALUE:    NOTES:  * VARIABLE  DESCRIPTION OF USAGE:                VALUE:   NOTES:
--------  ---------------------------------  --------  ------- * --------  -----------------------------------  -------  -------
SUNITS    UNITS SYSTEM USED IN COMPUTATIONS  ENGLISH           *

***** GRIDSPEC CARD:  SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE  DESCRIPTION OF USAGE:              VALUE:    NOTES:  * VARIABLE  DESCRIPTION OF USAGE:                VALUE:   NOTES:
--------  ---------------------------------  --------  ------- * --------  -----------------------------------  -------  -------
GRTYPE    TYPE OF FINITE-DIFFERENCE GRID     RECTANG           * GUNITS    SYSTEM OF UNITS USED FOR THE GRID    ENGLISH
XCELL     NUMBER OF GRID CELLS, X DIRECTION        48          * YCELL     NUMBER OF GRID CELLS, Y DIRECTION          5
DX        SPATIAL STEPSIZE IN X DIRECTION       10.00          * DY        SPATIAL STEPSIZE IN Y DIRECTION        10.00

***** PRINTING OF FIELD ARRAY VARIABLES:   1 AREAS

       AREA  * STARTING  ENDING  STARTING  ENDING          *                                        *  VARIABLE FIELD
     NUMBER  *  X CELL   X CELL   Y CELL   Y CELL  NOTES:  * START AT   END AT   INTERVAL NOTES:    *  ARRAYS TO PRINT:  NOTES:
     ------  * --- ---   ------   ------   ------  ------  * --------   ------   -------- ------    *  --- -----------   ------
          1  * X=  1   X=  48   Y=  1    Y=  5             *                                        *  DAHKB

***** WAVCOND CARD:  NUMBER OF WAVE CONDITIONS:   1

    WAVE CONDITION NUMBER:   1

VARIABLE  DESCRIPTION OF USAGE:              VALUE:    NOTES:  * VARIABLE  DESCRIPTION OF USAGE:                VALUE:   NOTES:
--------  ---------------------------------  --------  ------- * --------  -----------------------------------  -------  -------
HDEEP     DEEPWATER WAVE HEIGHT                  1.00          * TDEEP     WAVE PERIOD                             8.00
ZDEEP     DEEPWATER WAVE ANGLE                   0.00          * DIFFR     DIFFRACTION SIMULATED                YES
CNTRANG   OFFSHORE CONTOUR ANGLE                 0.00          *
1 08/15/91    C O A S T A L   M O D E L I N G   S Y S T E M   ( C M S ) :  R C P W A V ,   V E R S I O N   1 . 0    11:02:35
```

Figure 5-8. Sample output listing

64. Each record is summarized in tabular form with a heading containing its record identification label followed by a brief description of that record's function. A table is composed of each variable's name, a description of that variable (including its units, when applicable), and an error diagnostic note.

65. RCPWAVE contains error diagnostic features that inspect an input data set for possible errors. These features include: (a) comparing an inputted value against a range of quantities that are representative for that variable, (b) checking for misspelled character data, and (c) checking for missing data. The error diagnostic note can be assigned one of three character strings, which are (a) "FATAL" for errors where the model cannot execute given the value supplied, (b) "WARN" for data that are outside the range of values typically selected for that variable, and (c) a null string for instances where an error condition has not been identified. Although this model contains error diagnostic capabilities, the user should thoroughly inspect the input data summary to ensure that the data are correct.

66. Field arrays (e.g., bathymetry, wave heights, angle, numbers, breaker indices) are printed along with the input data summary by including one or more PRWINDOW records. Variable WPRVAR on record PRWINDOW is used to specify which field arrays are to be printed (e.g. WPRVAR = B for breaker indices). The breaker index is a flag to distinguish cells where wave breaking occurs (indicated with a B), from cells where wave breaking does not occur (indicated with a .). The user can specify printing of subgrid regions as opposed to the entire grid, if they so choose. This is done by specifying the x- and y-boundaries of a subgrid region with variables WXCEL1, WXCEL2, WYCEL1, and WYCEL2.

67. Plotting wave rays is facilitated by adding a PLOTREC record to the input data set. With this record, wave angles are saved for every grid cell in the computational domain for any number of wave conditions. The wave angle data is then used by program RAYPLOT in CMSPOST to generate wave ray plots.

68. Two examples are included in this section to demonstrate RCPWAVE's capabilities. The model was used to simulate wave conditions at the CERC's Field Research Facility (FRF) in Duck, North Carolina, and at Homer Spit, Alaska.

Duck, North Carolina

69. The FRF is located on the northern North Carolina coast. The selected study area measured 900 m in the x- (on-offshore) direction and 1,200 m in the y- (longshore) direction. The grid was composed of 75 cells in the x-direction and 50 cells in the y-direction, with a cell size of 12 by 24 m, respectively. Bathymetry contours off the Duck, North Carolina, coast are generally straight and parallel to the coastline, except in the immediate vicinity of the FRF pier (Figure 5-9). The pier's presence has caused the formation of a deep scour hole along much of its length. Actual depth values (relative to mean sea level (msl)) were provided for each cell in the study grid. The total water depth matrix was computed by simply adding half of the mean tide range (0.5 m) to each depth value. Two wave conditions were considered: (a) $H_0 = 2$ m, $T = 12$ sec, and $\theta_0 = 20$ deg and (b) $H_0 = 1.5$ m, $T = 8$ sec, and $\theta_0 = -35$ deg. The input data set is given in Appendix 5-B for details of each record.

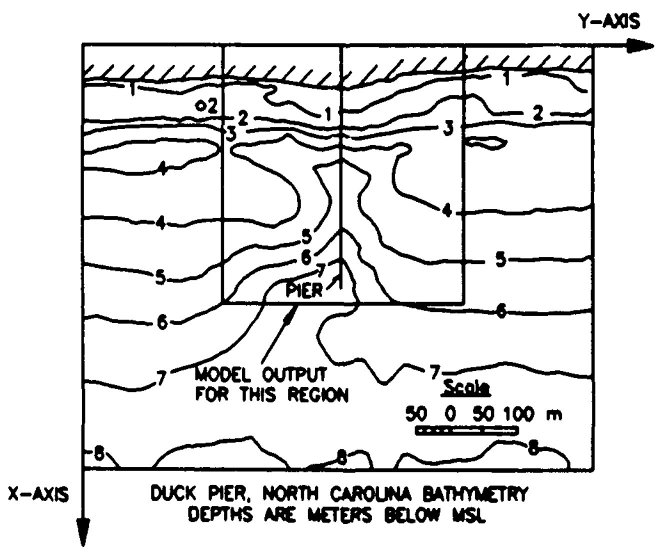

Figure 5-9. Bathymetric contours at Duck, North Carolina

70. A wave ray plot for each of the two wave conditions is given in Figures 5-10 and 5-11 for the entire computational domain. The wave rays tend to diverge from the scour hole along the pier and converge on the adjacent shoals, as expected. Model results (wave angles, heights, and breaker indices only) were also printed (Table 5-3) for the subgrid region shown in Figure 5-9. The breaker indices show wave breaking on the shoals and farther shoreward in the vicinity of the pier.

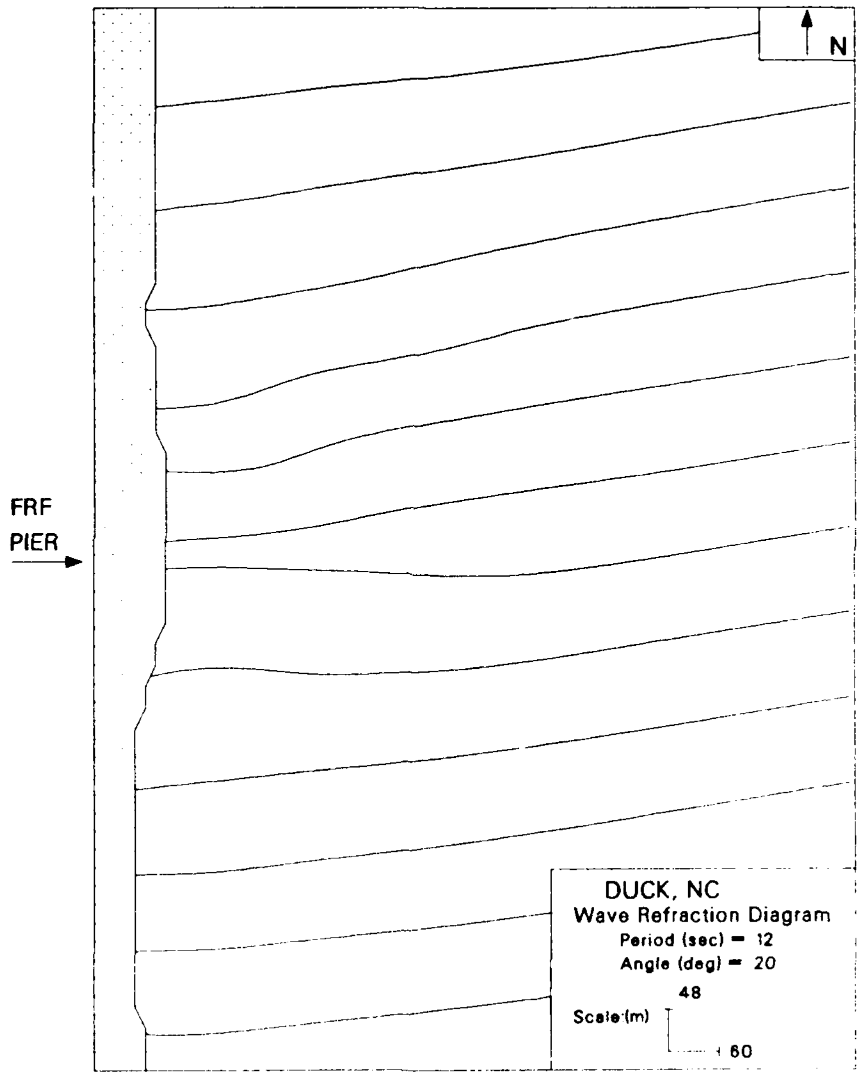

Figure 5-10. Wave rays for wave condition 1 at Duck, North Carolina

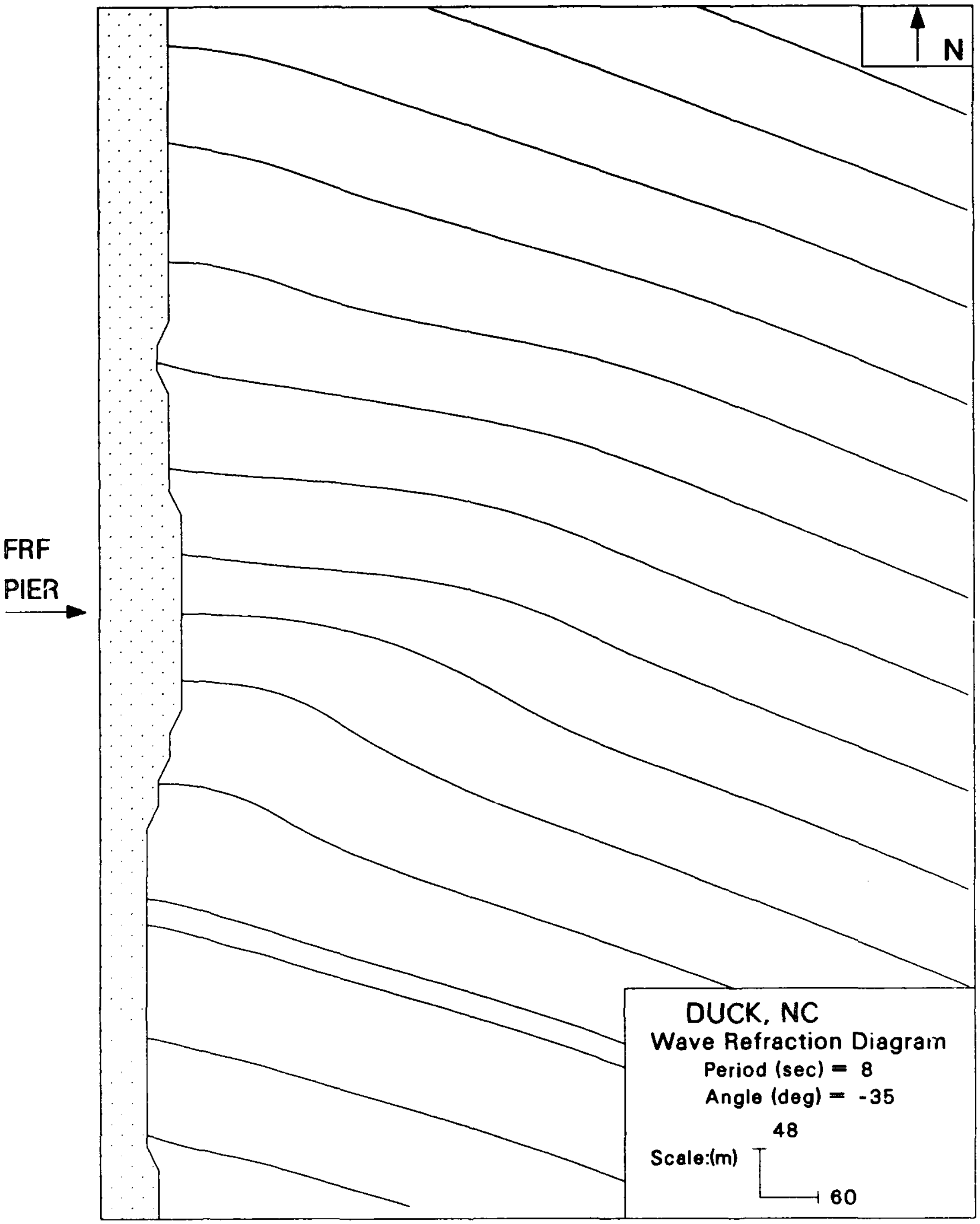

Figure 5-11. Wave rays for wave condition 2 at Duck, North Carolina

Table 5-3

Output Summary for Duck, North Carolina, Simulation

COASTAL MODELING SYSTEM (CMS): RCPWAV, VERSION 1.0

---- FIELD RESEARCH FACILITY (DUCK, NC) EXAMPLE ----

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	METRIC		*				

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		*	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	METRIC	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	75		*	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	50	
DX	SPATIAL STEPSIZE IN X DIRECTION	12.00		*	DY	SPATIAL STEPSIZE IN Y DIRECTION	24.00	

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER	*	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	*	START AT	END AT	INTERVAL	NOTES:	*	VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1	*	X= 1	X= 50	Y= 11	Y= 41		*					*	DAHB	

***** *WAVCOND CARD: NUMBER OF WAVE CONDITIONS: 2*

BREAKING INDEX

	I= 13	14	15	16	17	18	19	20	21	22	23	24
J= 41	B	.	.	.	.	.	.	.	.	.	.	.
J= 40	B	.	.	.	.	.	.	.	.	.	.	.
J= 39	B	.	.	.	.	.	.	.	.	.	.	.
J= 38	B	.	.	.	.	.	.	.	.	.	.	.
J= 37	B	.	.	.	.	.	.	.	.	.	.	.
J= 36	B	B	.	.	.	.	.	.	.	.	.	.
J= 35	B	B	.	.	.	.	.	.	.	.	.	.
J= 34	B	B	.	.	.	.	.	.	.	.	.	.
J= 33	B	B	.	.	.	.	.	.	.	.	.	.
J= 32	B	B	.	.	.	.	.	.	.	.	.	.
J= 31	B	B	B	.	.	.	.	.	.	.	.	.
J= 30	B	B	B	.	.	.	.	.	.	.	.	.
J= 29	B	B	B	.	.	.	.	.	.	.	.	.
J= 28	B	B	B	.	.	.	.	.	.	.	.	.
J= 27	B	B	.	.	.	.	.	.	.	.	.	.
J= 26	B	B	.	.	.	.	.	.	.	.	.	.
J= 25	B	B	.	.	.	.	.	.	.	.	.	.
J= 24	B	B	B	.	.	.	.	.	.	.	.	.
J= 23	B	B	.	.	.	.	.	.	.	.	.	.
J= 22	B	B	.	.	.	.	.	.	.	.	.	.
J= 21	B	.	.	.	.	.	.	.	.	.	.	.
J= 20	B	B	.	.	.	.	.	.	.	.	.	.
J= 19	B	B	.	.	.	.	.	.	.	.	.	.

Homer Spit, Alaska

71. Homer Spit is a narrow peninsula 300 to 1,500 feet wide, extending approximately 4-1/2 miles from northwest to southeast into Kachemak Bay, an appendage of lower Cook Inlet in southcentral Alaska (Figure 5-12). The selected study area measured 7.5 miles in the x- (on-offshore) direction and 13 miles in the y- (longshore) direction. The grid was composed of 96 cells in the x-direction and 83 cells in the y-direction, with a cell size of 416.7 by 833.3 ft. Bathymetry in the vicinity of Homer Spit is complicated (Figure 5-13). Actual depth values (relative to mean lower low water (mllw)) were provided for each cell in the study grid. One wave condition was considered: $H_0 = 8$ ft, $T = 10$ sec, and $\theta_0 = -45$ deg. The input data set is given in Appendix 5-C for details of each record.

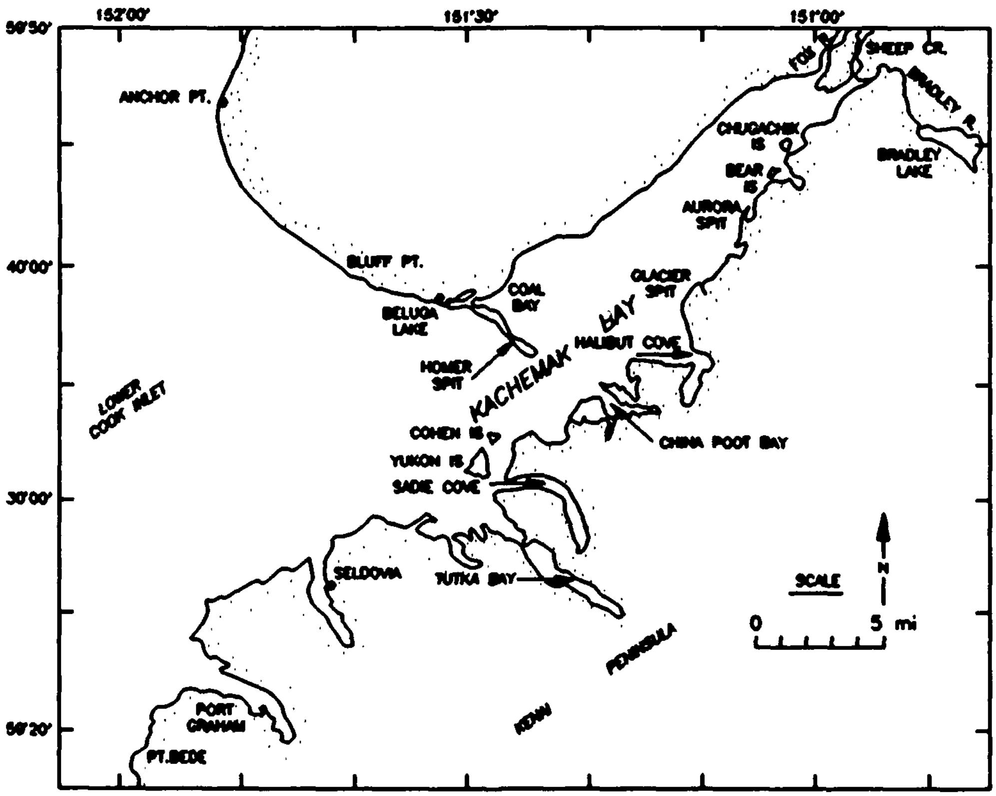

Figure 5-12. Map of Homer Spit, Alaska

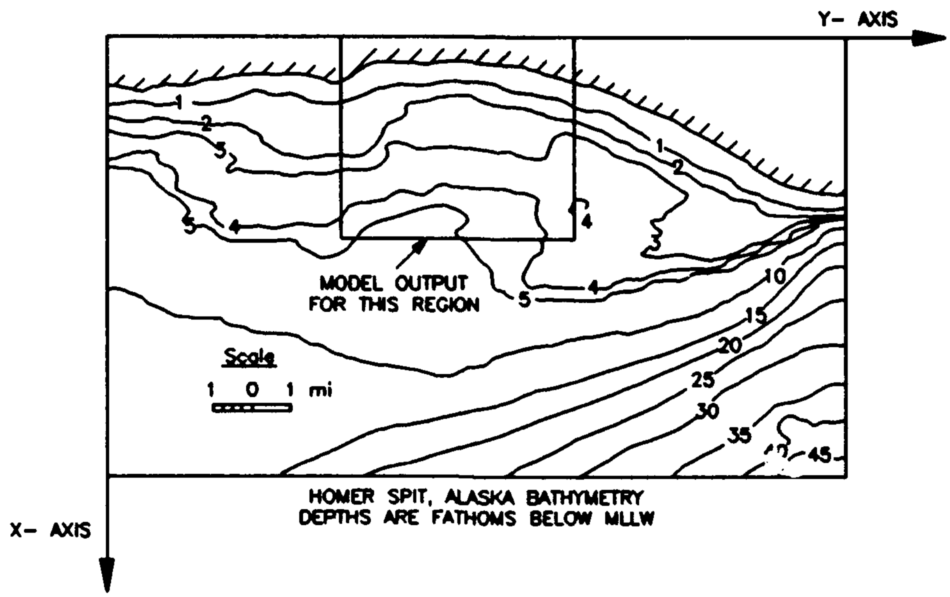

Figure 5-13. Bathymetric contours at Homer Spit, Alaska

72. A wave ray plot of model results is given in Figure 5-14 for the entire grid. The wave rays bend towards the shoals, as expected. Model results (wave heights, angles, numbers, and breaker indices) were also printed for cells I=1 to I=50 and J=25 to J=55 (Table 5-4).

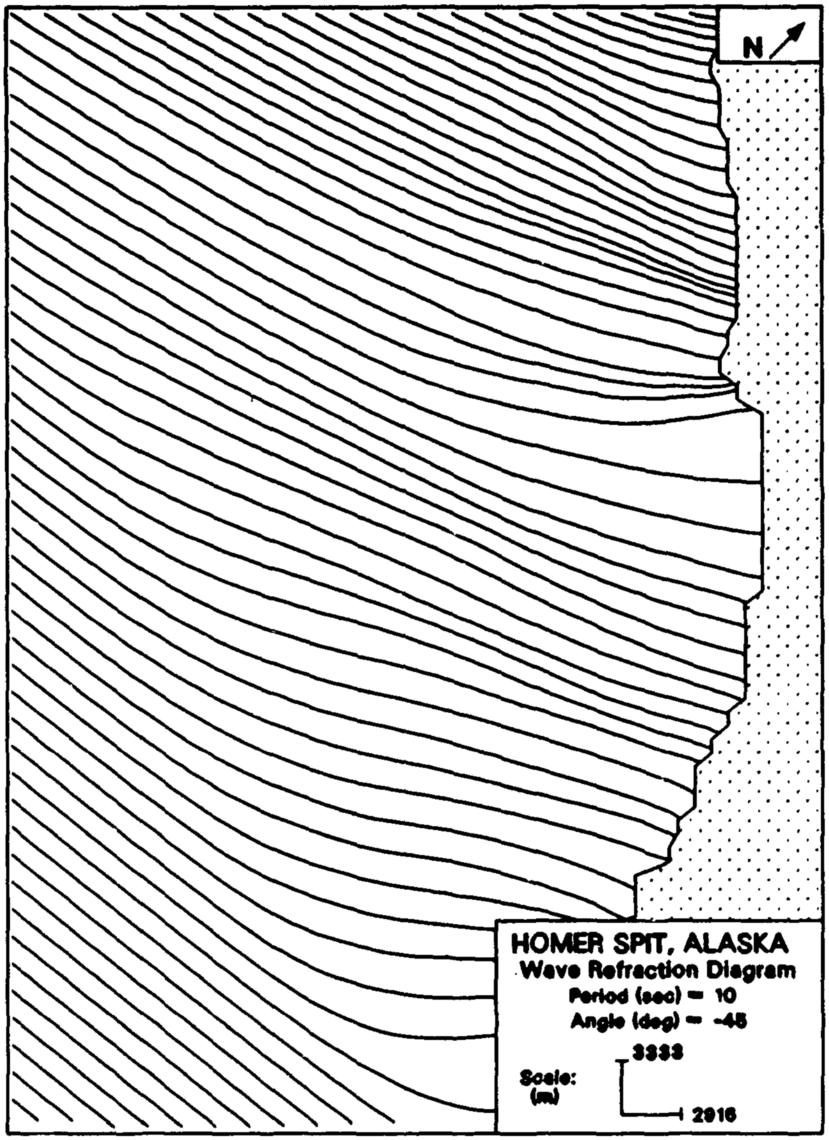

Figure 5-14. Wave rays for wave condition 1 at Homer Spit, Alaska

Table 5-4

Output Summary for Homer Spit, Alaska, Simulation

COASTAL MODELING SYSTEM (CMS): RCPWAV, VERSION 1.0

---- HOMER SPIT, ALASKA EXAMPLE ----

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	* VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*			

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	* VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		* GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	96		* YCELL	NUMBER OF GRID CELLS, Y DIRECTION	83	
DX	SPATIAL STEPSIZE IN X DIRECTION	416.70		* DY	SPATIAL STEPSIZE IN Y DIRECTION	833.30	

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER	*	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	*	START AT	END AT	INTERVAL	NOTES:	*	VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1	*	X= 1	X= 96	Y= 1	Y= 83		*					*	DAHB	

***** WAVCOND CARD: NUMBER OF WAVE CONDITIONS: 1

WAVE CONDITION NUMBER: 1

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	* VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
HDEEP	DEEPWATER WAVE HEIGHT	8.00		* TDEEP	WAVE PERIOD	10.00	
ZDEEP	DEEPWATER WAVE ANGLE	-45.00		* DIFFR	DIFFRACTION SIMULATED	YES	
CNTRANG	OFFSHORE CONTOUR ANGLE	0.00		*			

COASTAL MODELING SYSTEM (CMS): RCPWAV, VERSION 1.0

**** BATHSPEC CARD: SPECIFICATION OF BATHYMETRY/TOPOGRAPHY -

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	* VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
BUNITS	SYSTEM OF UNITS FOR DEPTH DATA	FEET		* BSEQ	READ SEQUENCE FOR DEPTH DECK	YX	
WDATUM	DATUM FOR WATER DEPTHS	0.000		* LDATUM	DATUM FOR LAND ELEVATIONS	0.000	
DLIMIT	MAXIMUM DEPTH ALLOWED	-6000.0		* BFORM	FORMAT OF DEPTH DATA	(10F8.0)	

NUMBER OF ELEVATION CHANGES = 0

****
*** INPUT PROCESSING COMPLETED:
FATAL ERRORS= 0 WARNINGS = 0
****

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APPENDIX 5-A: RCPWAVE DATA SPECIFICATION RECORDS

Model Control Specifications

(Req)	GENSPECS	Specify general title and system of units

Grid Description

(Req)	GRIDSPEC	Specify general grid characteristics

Physical Characteristics

(Req)	BATHSPEC	Specify characteristics of bathymetry/topography
(Req)	--	Two-dimensional array of bathymetric/topographic data
(Opt)	CHNGBATH	Specify changes to the bathymetric data
(Req)	WAVCOND	Specify deepwater wave conditions
(Opt)	CONVERG	Specify changes to the convergence criteria

Output Specifications

(Req)	PRWINDOW	Specify location of a print window
(Opt)	PLOTREC	Specify saving data for wave ray plot

CMS Data Specification: GENSPECS Record: (Req)

Purpose: Specify general title and system of units.

Field	Variable	Type	Status	Default	Permitted Data	Variable Definition
1	CARDID	Char *8	(Req)		GENSPECS	Record identifier.
2-9	TITLE	Char *64	(Opt)		A*	General title for simulation.
10	SUNITS	Char *8	(Opt)	ENGLISH	ENGLISH METRIC	Declares the system of units for model computations and results.

UNIT	ENGLISH (SI)	METRIC (British)
Length	ft	m
Time	sec	sec

CMS Data Specification: GRIDSPEC Record: (Req)
Purpose: Specify general computational grid characteristics.

Field	Variable	Type	Status	Default	Permitted Data	Variable Definition
1	CARDID	Char *8	(Req)		GRIDSPEC	Record identifier.
2	GRTYPE	Char *8	(Opt)	RECTANG	RECTANG	Cartesian system with constant-spaced grid cells.
3	GUNITS	Char *8	(Opt)	ENGLISH	ENGLISH METRIC	System of units for grid data.
4	XCELLS	Integer	(Req)		+I*	Number of grid cells in x-direction.
5	YCELLS	Integer	(Req)		+I*	Number of grid cells in y-direction.
6	DX	Real	(Req)		+R*	Spatial stepsize in x-direction (in GUNITS).
7	DY	Real	(Req)		+R*	Spatial stepsize in y-direction (in GUNITS).

CMS Data Specification: BATHSPEC Record: (Req)

Purpose: Specify general characteristics of the bathymetry/topography data.

Field	Variable	Type	Status	Default	Permitted Data	Variable Definition
1	CARDID	Char *8	(Req)		BATHSPEC	Record identifier.
2	BUNITS	Char *8	(Opt)	FEET	FEET METERS FATHOMS	Declares the units for the following bathymetry/topograghy data.
3	WDATUM	Real	(Opt)	0.	R*	Negative values of bathymetry (depths) are added to this datum value (in BUNITS)
4	LDATUM	Real	(Opt)	0.	R*	Positive values of topography are added to this datum (in BUNITS).
5	DLIMIT	Real	(Opt)	-6000. ft	R*	A limiting water depth (deeper values are set to this value in BUNITS).
6	BSEQ	Char *8	(Opt)	XY	XY -XY X-Y -X-Y YX -YX Y-X -Y-X	The 2-D array of bathymetry/topography which follows this record is read in a sequence specified by this mnemonic code (see notes for the conventions represented by these mnemonics).
7-8	BFORM	Char *16	(Opt)	(8G10.3)	A*	Format used to read the following 2-D array of bathymetry/topography values.
9-10	BNAME	Char *16	(Opt)		A*	Name of bathymetry/topography set.

(Continued)

BATHSPEC Record (Concluded)

NOTES:

(1) The actual 2-D array of bathymetry/topography data follows this record.

(2) Conventions for 2-D array read sequence mnemonics:

```
***************** SEQ = XY *******************
      DO 1 J=1,YCELLS
  1   READ(LUN,FORM) (VAR(I,J),I=1,XCELLS)

***************** SEQ = -XY *******************
      DO 2 J=1,YCELLS
  2   READ(LUN,FORM) (VAR(I,J),I=XCELLS,1,-1)

***************** SEQ = X-Y *******************
      DO 3 J=YCELLS,1,-1
  3   READ(LUN,FORM) (VAR(I,J),I=1,XCELLS)

***************** SEQ =-X-Y *******************
      DO 4 J=YCELLS,1,-1
  4   READ(LUN,FORM) (VAR(I,J),I=XCELLS,1,-1)

***************** SEQ = YX ********************
      DO 5 I=1,XCELLS
  5   READ(LUN,FORM) (VAR(I,J),J=1,YCELLS)

***************** SEQ = -YX *******************
      DO 6 I=1,XCELLS
  6   READ(LUN,FORM) (VAR(I,J),J=YCELLS,1,-1)

***************** SEQ = Y-X *******************
      DO 7 I=XCELLS,1,-1
  7   READ(LUN,FORM) (VAR(I,J),J=1,YCELLS)

**************** SEQ = -Y-X *******************
      DO 8 I=XCELLS,1,-1
  8   READ(LUN,FORM) (VAR(I,J),J=YCELLS,1,-1)
```

CMS Data Specification: CHNGBATH Record: (Opt)
Purpose: Specify changes to the bathymetry data.

Field	Variable	Type	Status	Default	Permitted Data	Variable Definition
1	CARDID	Char *8	(Req)		CHNGBATH	Record identifier.
2	BATH	Real	(Req)		R*	New bathymetry/topography value (in BUNITS ... the two datum shift values LDATUM and WDATUM will not be applied to this value).
3	X1INDX	Integer	(Req)		I*	Declares the location of the bathymetry /topography value as a point, line, or a rectangular patch in the grid.
4	Y1INDX	Integer	(Req)		I*	
5	X2INDX	Integer	(Opt)	0	I*	
6	Y2INDX	Integer	(Opt)	0	I*	

NOTE:
(1) Use one CHNGBATH record per value (no changes if this record is omitted).
(2) All CHNGBATH records must follow two-dimensional bathymetry array.

CMS Data Specification: WAVCOND Record: (Req)
Purpose: Specify deepwater wave conditions

Field	Variable	Type	Status	Default	Permitted Data	Variable Definition
1	CARDID	Char *8	(Req)		WAVCOND	Record identifier.
2	HDEEP	Real	(Req)		+R*	Deepwater wave height
3	TDEEP	Real	(Req)		+R*	Wave period
4	ZDEEP	Real	(Req)		+R*	Deepwater wave angle
5	CNTRANG	Real	(Opt)	0.0	R*	Offshore contour angle
6	DIFFR	Char *8	(Opt)	YES	YES NO	Determine if diffractive effects are included

CMS Data Specification: CONVERG Record: (Opt)
Purpose: Specify changes to convergence criteria

Field	Variable	Type	Status	Default	Permitted Data	Variable Definition
1	CARDID	Char *8	(Req)		CONVERG	Record identifier.
2	HCONVR	Real	(Opt)	0.0005 ft	+R*	Wave height convergence criteria
3	SCONVR	Real	(Opt)	0.00025 rad	+R*	Wave angle convergence criteria
4	ITAMX	Integer	(Opt)	50	+I*	Maximum number of iterations for height/angle calculations
5	IDIFF	Integer	(Opt)	15	+I*	Maximum number of iterations for diffraction
6	STABL	Real	(Opt)	0.4	+R*	Stability factor
7	DECAY	Real	(opt)	0.2	+R*	Decay factor

CMS Data Specificaiton: PRWINDOW Record: (Opt)
Purpose: Specify location of a print window.

Field	Varaiable	Type	Status	Default	Permitted Data	Variable Definition
1	CARDID	Char *8	(Req)		PRWINDOW	Record identifier.
2	WXCEL1	Integer	(Opt)	1	+I*	Cell indices declaring the grid subregion or window for printing the selected variables. The window will be bounded by (and include) the region
3	WXCEL2	Integer	(Opt)	XCELLS	+I*	from (WXCEL1,WYCEL1) to (WXCEL2,WYCEL2).
4	WYCEL1	Integer	(Opt)	1	+I*	
5	WYCEL2	Integer	(Opt)	YCELLS	+I*	
9-10	WPRVAR	Char *16	(Opt)	DAHKB	D	Bathymetry value.
					A	Wave angle.
					H	Wave height.
					K	Wave number
					B	Breaking index

Note: Use 1 PRWINDOW record/window (in space).

CMS Data Specification: PLOTREC Record: (Opt)
Purpuse: Specify saving data for wave ray plot

Field	Variable	Type	Status	Default	Permitted Data	Variable Definition
1	CARDID	Char *8	(Req)		PLOTREC	Record identifier.

APPENDIX 5-B: INPUT DATA SET FOR DUCK, NORTH CAROLINA

```
GENSPECS        FIELD RESEARCH FACILITY (DUCK, NC) EXAMPLE
METRIC
GRIDSPEC                METRIC      75      50    12.0    24.0
PRWINDOW       1            50      11      41    DAHB
BATHSPEC  METERS                   0.5              XY (9F8.2)
    5.76    6.05    3.13    2.59    1.18    -.13   -1.62   -1.90   -1.03
    -.92   -1.20   -1.44   -1.86   -2.29   -2.78   -3.08   -3.54   -3.83
   -4.02   -4.08   -4.05   -3.99   -3.88   -3.81   -3.69   -3.67   -3.69
   -3.75   -3.84   -3.93   -4.05   -4.22   -4.33   -4.45   -4.53   -4.69
   -4.76   -4.94   -5.03   -5.12   -5.24   -5.37   -5.51   -5.64   -5.72
   -5.82   -5.92   -5.97   -6.10   -6.22   -6.28   -6.40   -6.52   -6.60
   -6.70   -6.74   -6.80   -6.88   -6.96   -7.01   -7.04   -7.16   -7.28
   -7.31   -7.36   -7.41   -7.56   -7.62   -7.68   -7.74   -7.86   -7.92
   -8.07   -8.14   -8.19
    5.61    4.95    3.49    2.23    1.06    -.23   -1.22   -1.55   -1.34
   -1.14   -1.24   -1.53   -1.83   -2.38   -2.87   -3.23   -3.53   -3.83
   -4.05   -4.11   -4.08   -4.00   -3.89   -3.80   -3.72   -3.68   -3.70
   -3.75   -3.83   -3.92   -4.07   -4.23   -4.34   -4.43   -4.53   -4.65
   -4.78   -4.92   -5.01   -5.11   -5.22   -5.35   -5.49   -5.61   -5.69
   -5.78   -5.90   -5.99   -6.07   -6.16   -6.28   -6.39   -6.48   -6.58
   -6.67   -6.74   -6.80   -6.88   -6.94   -6.99   -7.05   -7.15   -7.25
   -7.30   -7.34   -7.43   -7.53   -7.61   -7.67   -7.74   -7.84   -7.93
   -8.03   -8.09   -8.14
    5.45    4.77    3.65    2.27    1.14    -.13   -1.02   -1.38   -1.43
   -1.36   -1.40   -1.61   -1.89   -2.47   -3.01   -3.37   -3.67   -3.94
   -4.15   -4.20   -4.17   -4.06   -3.91   -3.81   -3.74   -3.70   -3.71
   -3.75   -3.83   -3.91   -4.05   -4.20   -4.31   -4.40   -4.51   -4.62
   -4.75   -4.87   -4.97   -5.09   -5.18   -5.28   -5.42   -5.53   -5.62
   -5.72   -5.85   -5.94   -6.03   -6.12   -6.24   -6.36   -6.44   -6.55
   -6.62   -6.72   -6.78   -6.86   -6.91   -6.96   -7.02   -7.13   -7.21
   -7.26   -7.30   -7.40   -7.50   -7.59   -7.65   -7.71   -7.81   -7.89
   -7.98   -8.01   -8.06
    5.66    4.90    3.67    2.44    1.32    -.00    -.91   -1.30   -1.50
   -1.55   -1.56   -1.66   -1.94   -2.55   -3.10   -3.50   -3.83   -4.08
   -4.25   -4.29   -4.27   -4.17   -3.95   -3.84   -3.76   -3.71   -3.70
   -3.74   -3.82   -3.89   -4.02   -4.15   -4.27   -4.36   -4.47   -4.58
   -4.69   -4.79   -4.90   -5.05   -5.14   -5.23   -5.35   -5.46   -5.56
   -5.67   -5.78   -5.88   -6.00   -6.10   -6.21   -6.31   -6.40   -6.51
   -6.59   -6.69   -6.75   -6.84   -6.88   -6.93   -6.99   -7.11   -7.17
   -7.22   -7.26   -7.37   -7.47   -7.56   -7.63   -7.70   -7.78   -7.84
   -7.91   -7.95   -7.99
    6.39    5.24    3.49    2.59    1.52     .02    -.91   -1.30   -1.55
   -1.68   -1.66   -1.59   -1.92   -2.59   -3.13   -3.57   -3.93   -4.16
   -4.32   -4.35   -4.33   -4.25   -4.02   -3.84   -3.77   -3.69   -3.67
   -3.73   -3.79   -3.88   -3.98   -4.12   -4.23   -4.34   -4.43   -4.55
   -4.64   -4.73   -4.86   -5.01   -5.11   -5.20   -5.32   -5.44   -5.55
   -5.65   -5.75   -5.85   -5.98   -6.07   -6.20   -6.29   -6.38   -6.49
   -6.58   -6.66   -6.76   -6.82   -6.87   -6.91   -6.98   -7.08   -7.16
   -7.19   -7.24   -7.35   -7.46   -7.53   -7.62   -7.70   -7.77   -7.81
   -7.87   -7.93   -7.98
    6.37    5.24    3.51    2.60    1.54     .06    -.88   -1.28   -1.54
   -1.69   -1.67   -1.60   -1.94   -2.60   -3.14   -3.58   -3.95   -4.17
   -4.33   -4.36   -4.33   -4.24   -4.00   -3.83   -3.76   -3.68   -3.67
   -3.72   -3.79   -3.88   -3.97   -4.11   -4.23   -4.33   -4.42   -4.53
```

-4.63	-4.71	-4.84	-4.99	-5.09	-5.20	-5.31	-5.43	-5.53
-5.64	-5.74	-5.84	-5.98	-6.07	-6.20	-6.28	-6.38	-6.49
-6.59	-6.67	-6.76	-6.83	-6.88	-6.92	-6.99	-7.09	-7.16
-7.20	-7.25	-7.36	-7.47	-7.54	-7.63	-7.70	-7.77	-7.81
-7.87	-7.93	-7.97						
5.78	4.97	3.70	2.55	1.44	.18	-.74	-1.18	-1.46
-1.59	-1.62	-1.68	-2.01	-2.61	-3.18	-3.59	-3.97	-4.18
-4.32	-4.34	-4.30	-4.15	-3.91	-3.78	-3.72	-3.67	-3.66
-3.72	-3.80	-3.87	-3.97	-4.10	-4.22	-4.31	-4.39	-4.50
-4.59	-4.69	-4.80	-4.95	-5.05	-5.18	-5.29	-5.40	-5.51
-5.62	-5.72	-5.84	-5.98	-6.09	-6.18	-6.29	-6.39	-6.52
-6.60	-6.73	-6.79	-6.88	-6.93	-6.98	-7.05	-7.16	-7.21
-7.27	-7.30	-7.41	-7.50	-7.59	-7.66	-7.72	-7.81	-7.86
-7.92	-7.95	-7.98						
5.77	4.93	3.73	2.53	1.43	.28	-.58	-1.06	-1.35
-1.48	-1.55	-1.65	-2.05	-2.64	-3.23	-3.61	-4.02	-4.22
-4.35	-4.35	-4.25	-4.06	-3.83	-3.68	-3.65	-3.62	-3.63
-3.69	-3.78	-3.86	-3.94	-4.06	-4.20	-4.28	-4.34	-4.44
-4.53	-4.65	-4.77	-4.89	-4.99	-5.12	-5.25	-5.38	-5.48
-5.59	-5.70	-5.83	-5.99	-6.09	-6.18	-6.30	-6.42	-6.58
-6.66	-6.81	-6.86	-6.96	-7.03	-7.09	-7.14	-7.25	-7.32
-7.37	-7.40	-7.51	-7.59	-7.67	-7.72	-7.78	-7.88	-7.93
-8.00	-8.02	-8.04						
5.98	5.08	3.61	2.55	1.46	.26	-.56	-1.03	-1.34
-1.49	-1.57	-1.66	-2.04	-2.68	-3.23	-3.64	-4.04	-4.28
-4.39	-4.34	-4.18	-3.98	-3.76	-3.61	-3.58	-3.57	-3.59
-3.66	-3.76	-3.86	-3.92	-4.04	-4.17	-4.25	-4.32	-4.40
-4.49	-4.63	-4.75	-4.86	-4.96	-5.09	-5.23	-5.36	-5.48
-5.60	-5.71	-5.87	-6.02	-6.12	-6.22	-6.34	-6.47	-6.63
-6.76	-6.88	-6.95	-7.05	-7.13	-7.19	-7.23	-7.34	-7.43
-7.46	-7.51	-7.60	-7.69	-7.76	-7.80	-7.86	-7.94	-8.02
-8.08	-8.09	-8.11						
6.33	6.84	3.41	2.69	1.98	.37	-.77	-.88	-1.23
-1.35	-1.47	-1.45	-1.89	-2.73	-3.26	-3.58	-3.94	-4.36
-4.42	-4.45	-4.32	-4.02	-3.76	-3.60	-3.57	-3.54	-3.58
-3.63	-3.74	-3.84	-3.93	-3.99	-4.15	-4.22	-4.30	-4.39
-4.48	-4.60	-4.69	-4.82	-4.94	-5.09	-5.21	-5.33	-5.46
-5.58	-5.70	-5.84	-5.97	-6.07	-6.22	-6.31	-6.43	-6.64
-6.80	-6.89	-6.95	-7.07	-7.17	-7.20	-7.23	-7.34	-7.46
-7.50	-7.55	-7.60	-7.74	-7.80	-7.84	-7.89	-7.93	-8.08
-8.10	-8.13	-8.14						
5.91	5.00	3.56	2.42	1.28	.12	-.71	-1.24	-1.54
-1.71	-1.77	-1.79	-2.04	-2.62	-3.21	-3.60	-4.01	-4.27
-4.35	-4.24	-4.00	-3.79	-3.62	-3.53	-3.53	-3.55	-3.59
-3.67	-3.78	-3.88	-3.95	-4.05	-4.18	-4.27	-4.35	-4.42
-4.52	-4.66	-4.80	-4.90	-5.00	-5.15	-5.28	-5.42	-5.54
-5.67	-5.80	-5.97	-6.12	-6.23	-6.34	-6.46	-6.58	-6.72
-6.84	-6.96	-7.03	-7.14	-7.21	-7.26	-7.30	-7.39	-7.48
-7.53	-7.58	-7.66	-7.74	-7.81	-7.86	-7.91	-7.98	-8.05
-8.11	-8.13	-8.16						
6.24	5.76	3.36	2.47	1.05	.08	-1.12	-1.52	-1.83
-2.03	-2.21	-1.89	-1.83	-2.59	-3.19	-3.65	-4.05	-4.37
-4.46	-4.19	-3.89	-3.63	-3.49	-3.46	-3.49	-3.54	-3.62
-3.68	-3.80	-3.93	-4.00	-4.08	-4.19	-4.29	-4.38	-4.46

-4.54	-4.69	-4.84	-4.89	-5.03	-5.19	-5.31	-5.47	-5.58
-5.73	-5.88	-6.03	-6.19	-6.33	-6.43	-6.53	-6.66	-6.77
-6.88	-6.99	-7.07	-7.21	-7.27	-7.31	-7.35	-7.41	-7.54
-7.57	-7.62	-7.68	-7.74	-7.85	-7.88	-7.93	-7.99	-8.05
-8.11	-8.16	-8.19						
5.96	5.07	3.50	2.24	1.01	-.10	-.98	-1.46	-1.70
-1.83	-1.90	-1.86	-2.00	-2.50	-3.09	-3.49	-3.88	-4.16
-4.24	-4.04	-3.75	-3.56	-3.44	-3.39	-3.44	-3.51	-3.57
-3.66	-3.79	-3.90	-3.99	-4.10	-4.23	-4.34	-4.44	-4.53
-4.64	-4.81	-4.96	-5.03	-5.15	-5.30	-5.44	-5.62	-5.70
-5.85	-5.98	-6.14	-6.31	-6.41	-6.51	-6.61	-6.72	-6.85
-6.95	-7.06	-7.13	-7.22	-7.28	-7.33	-7.37	-7.44	-7.53
-7.58	-7.63	-7.71	-7.77	-7.84	-7.89	-7.95	-8.02	-8.07
-8.12	-8.15	-8.18						
6.55	5.59	3.38	2.00	.85	-.50	-1.28	-1.56	-1.55
-1.46	-1.56	-1.74	-1.98	-2.37	-2.72	-3.18	-3.56	-3.92
-3.97	-3.71	-3.38	-3.30	-3.21	-3.25	-3.32	-3.38	-3.50
-3.62	-3.74	-3.86	-3.99	-4.11	-4.24	-4.38	-4.49	-4.61
-4.75	-4.92	-5.05	-5.18	-5.33	-5.47	-5.62	-5.77	-5.90
-6.05	-6.21	-6.36	-6.49	-6.60	-6.71	-6.82	-6.91	-7.01
-7.10	-7.18	-7.24	-7.28	-7.32	-7.37	-7.43	-7.47	-7.53
-7.59	-7.65	-7.74	-7.80	-7.86	-7.91	-7.98	-8.05	-8.10
-8.14	-8.18	-8.21						
6.45	5.49	3.43	1.99	.84	-.43	-1.21	-1.51	-1.50
-1.40	-1.51	-1.69	-1.96	-2.36	-2.71	-3.16	-3.58	-3.91
-3.98	-3.77	-3.44	-3.33	-3.23	-3.25	-3.30	-3.37	-3.46
-3.57	-3.69	-3.83	-3.98	-4.12	-4.27	-4.43	-4.55	-4.69
-4.87	-5.08	-5.21	-5.33	-5.47	-5.61	-5.76	-5.90	-6.03
-6.22	-6.36	-6.44	-6.56	-6.67	-6.77	-6.87	-6.96	-7.06
-7.14	-7.21	-7.26	-7.30	-7.34	-7.38	-7.44	-7.49	-7.55
-7.60	-7.66	-7.74	-7.80	-7.86	-7.91	-7.98	-8.05	-8.10
-8.14	-8.17	-8.21						
6.09	5.24	3.49	2.15	.88	-.17	-1.04	-1.38	-1.27
-1.31	-1.40	-1.57	-1.91	-2.39	-2.77	-3.19	-3.66	-4.00
-4.14	-3.99	-3.69	-3.45	-3.31	-3.24	-3.27	-3.32	-3.38
-3.47	-3.60	-3.75	-3.97	-4.17	-4.39	-4.61	-4.81	-4.96
-5.23	-5.51	-5.66	-5.81	-5.98	-6.16	-6.29	-6.42	-6.52
-6.60	-6.71	-6.73	-6.81	-6.91	-6.96	-7.02	-7.07	-7.16
-7.23	-7.31	-7.35	-7.38	-7.40	-7.43	-7.49	-7.56	-7.64
-7.67	-7.72	-7.78	-7.83	-7.89	-7.95	-8.00	-8.05	-8.10
-8.14	-8.16	-8.19						
6.20	5.58	3.35	2.32	.97	-.14	-1.21	-1.43	-1.04
-1.13	-1.30	-1.53	-1.87	-2.36	-2.74	-3.16	-3.65	-4.06
-4.24	-4.07	-3.74	-3.47	-3.30	-3.21	-3.25	-3.29	-3.34
-3.43	-3.57	-3.71	-3.96	-4.17	-4.40	-4.66	-4.93	-5.08
-5.36	-5.65	-5.78	-5.98	-6.18	-6.40	-6.55	-6.65	-6.71
-6.79	-6.85	-6.88	-6.96	-7.03	-7.06	-7.12	-7.14	-7.21
-7.27	-7.34	-7.40	-7.42	-7.44	-7.46	-7.51	-7.58	-7.69
-7.69	-7.73	-7.79	-7.85	-7.91	-7.97	-8.01	-8.06	-8.10
-8.15	-8.16	-8.20						
6.12	5.20	3.52	2.27	1.28	.23	-.70	-1.12	-1.07
-1.07	-1.20	-1.42	-1.83	-2.38	-2.82	-3.32	-3.87	-4.28
-4.39	-4.29	-4.10	-3.85	-3.62	-3.47	-3.41	-3.37	-3.39
-3.45	-3.55	-3.68	-3.87	-4.07	-4.34	-4.57	-4.83	-5.13

-5.43	-5.71	-5.97	-6.22	-6.46	-6.67	-6.82	-6.96	-7.01
-7.02	-7.02	-7.04	-7.05	-7.09	-7.12	-7.14	-7.17	-7.22
-7.27	-7.33	-7.36	-7.39	-7.41	-7.43	-7.45	-7.50	-7.55
-7.59	-7.62	-7.68	-7.73	-7.78	-7.83	-7.87	-7.95	-8.01
-8.06	-8.08	-8.11						
6.65	6.13	3.32	2.34	1.72	.37	-1.01	-1.27	-.87
-.85	-1.08	-1.30	-1.81	-2.33	-2.84	-3.38	-4.03	-4.61
-4.70	-4.45	-4.43	-4.17	-3.83	-3.60	-3.42	-3.33	-3.30
-3.44	-3.42	-3.63	-3.73	-3.97	-4.25	-4.48	-4.78	-5.03
-5.40	-5.79	-6.10	-6.46	-6.77	-6.98	-7.07	-7.37	-7.25
-7.22	-7.21	-7.18	-7.16	-7.16	-7.16	-7.19	-7.17	-7.24
-7.29	-7.32	-7.35	-7.40	-7.41	-7.41	-7.41	-7.44	-7.50
-7.54	-7.56	-7.60	-7.68	-7.72	-7.76	-7.79	-7.87	-7.95
-8.01	-8.04	-8.07						
6.02	5.11	3.54	2.40	1.64	.65	-.36	-.87	-.93
-.97	-1.09	-1.30	-1.67	-2.27	-2.91	-3.58	-4.07	-4.40
-4.55	-4.51	-4.38	-4.20	-4.04	-3.85	-3.71	-3.60	-3.56
-3.62	-3.69	-3.80	-3.94	-4.13	-4.38	-4.64	-4.92	-5.24
-5.56	-5.83	-6.16	-6.53	-6.81	-6.99	-7.14	-7.24	-7.25
-7.22	-7.20	-7.18	-7.17	-7.17	-7.17	-7.17	-7.19	-7.23
-7.27	-7.32	-7.34	-7.37	-7.39	-7.40	-7.43	-7.47	-7.51
-7.55	-7.58	-7.63	-7.68	-7.73	-7.77	-7.81	-7.88	-7.95
-7.99	-8.00	-8.03						
6.29	5.96	3.37	2.39	2.05	1.12	-.24	-.99	-.79
-1.00	-1.09	-1.08	-1.47	-2.07	-2.94	-3.99	-4.28	-4.47
-4.69	-4.74	-4.34	-4.29	-4.28	-4.14	-3.94	-3.80	-3.80
-3.77	-3.80	-3.94	-4.03	-4.21	-4.41	-4.75	-4.93	-5.30
-5.59	-5.91	-6.27	-6.73	-6.97	-7.17	-7.30	-7.29	-7.34
-7.28	-7.23	-7.22	-7.22	-7.21	-7.19	-7.18	-7.19	-7.23
-7.28	-7.31	-7.34	-7.37	-7.38	-7.40	-7.43	-7.47	-7.52
-7.57	-7.59	-7.62	-7.65	-7.71	-7.76	-7.79	-7.86	-7.92
-7.95	-7.97	-7.99						
5.87	5.00	3.58	2.53	1.96	1.11	.07	-.61	-.81
-.88	-.96	-1.10	-1.40	-1.92	-2.68	-3.40	-3.81	-4.13
-4.47	-4.61	-4.60	-4.58	-4.54	-4.38	-4.21	-4.11	-4.09
-4.06	-4.07	-4.14	-4.28	-4.46	-4.66	-4.90	-5.17	-5.50
-5.79	-6.03	-6.41	-6.79	-7.01	-7.16	-7.28	-7.32	-7.31
-7.26	-7.21	-7.17	-7.14	-7.13	-7.12	-7.11	-7.12	-7.16
-7.21	-7.27	-7.29	-7.30	-7.32	-7.34	-7.39	-7.45	-7.51
-7.55	-7.58	-7.62	-7.66	-7.71	-7.76	-7.80	-7.86	-7.92
-7.96	-7.97	-7.99						
5.91	5.03	3.49	2.53	2.11	1.38	.26	-.57	-.74
-.76	-.83	-.93	-1.21	-1.62	-2.15	-2.75	-3.24	-3.94
-4.33	-4.68	-4.91	-5.00	-4.92	-4.75	-4.64	-4.49	-4.40
-4.35	-4.36	-4.45	-4.59	-4.83	-4.97	-5.17	-5.44	-5.69
-5.93	-6.28	-6.58	-6.93	-7.13	-7.26	-7.35	-7.41	-7.35
-7.29	-7.22	-7.14	-7.08	-7.08	-7.05	-7.03	-7.05	-7.08
-7.14	-7.19	-7.22	-7.23	-7.24	-7.25	-7.33	-7.41	-7.53
-7.57	-7.61	-7.64	-7.70	-7.73	-7.78	-7.83	-7.88	-7.92
-7.95	-7.98	-8.01						
6.11	5.19	3.55	2.53	2.05	1.37	.37	-.46	-.71
-.77	-.85	-.92	-1.19	-1.60	-2.07	-2.55	-3.08	-3.69
-4.21	-4.63	-4.89	-5.02	-5.06	-5.02	-4.95	-4.79	-4.67
-4.63	-4.66	-4.76	-4.89	-5.10	-5.23	-5.41	-5.62	-5.89

-6.12	-6.42	-6.73	-7.00	-7.19	-7.31	-7.38	-7.40	-7.36
-7.27	-7.18	-7.09	-7.02	-7.02	-6.99	-6.97	-6.98	-7.02
-7.05	-7.14	-7.19	-7.21	-7.22	-7.24	-7.32	-7.41	-7.50
-7.55	-7.58	-7.62	-7.68	-7.72	-7.77	-7.81	-7.87	-7.91
-7.96	-7.99	-8.01						
6.13	5.30	3.56	2.48	2.00	1.37	.39	-.43	-.68
-.78	-.87	-.94	-1.16	-1.57	-2.10	-2.60	-3.12	-3.67
-4.21	-4.65	-4.93	-5.10	-5.20	-5.25	-5.21	-5.10	-5.03
-5.04	-5.12	-5.20	-5.36	-5.45	-5.64	-5.74	-5.96	-6.40
-6.48	-6.71	-7.02	-7.19	-7.36	-7.42	-7.50	-7.51	-7.49
-7.34	-7.16	-7.02	-6.95	-6.93	-6.90	-6.89	-6.92	-6.95
-6.98	-7.01	-7.07	-7.13	-7.17	-7.20	-7.28	-7.35	-7.42
-7.45	-7.47	-7.52	-7.60	-7.66	-7.70	-7.73	-7.79	-7.87
-7.96	-8.00	-8.04						
5.90	5.31	3.41	2.35	1.89	1.29	.24	-.54	-.70
-.84	-.94	-1.03	-1.21	-1.64	-2.30	-2.92	-3.47	-4.09
-4.51	-4.85	-5.16	-5.31	-5.38	-5.47	-5.47	-5.51	-5.55
-5.55	-5.59	-5.70	-5.85	-5.96	-6.07	-6.28	-6.46	-6.86
-6.97	-7.10	-7.28	-7.49	-7.66	-7.67	-7.71	-7.76	-7.90
-7.81	-7.17	-6.96	-6.89	-6.85	-6.82	-6.83	-6.86	-6.92
-6.95	-6.97	-7.03	-7.10	-7.15	-7.19	-7.27	-7.33	-7.39
-7.43	-7.44	-7.48	-7.58	-7.64	-7.69	-7.71	-7.77	-7.85
-7.99	-8.06	-8.12						
6.25	5.43	3.30	2.35	1.92	1.21	.28	-.62	-.75
-.84	-.96	-1.02	-1.25	-1.78	-2.35	-2.72	-3.28	-3.84
-4.46	-4.68	-5.13	-5.27	-5.31	-5.38	-5.43	-5.51	-5.54
-5.44	-5.46	-5.53	-5.74	-5.83	-5.99	-6.21	-6.35	-6.47
-6.62	-6.75	-6.90	-7.03	-7.14	-7.25	-7.29	-7.31	-7.55
-7.61	-7.07	-6.84	-6.77	-6.76	-6.79	-6.83	-6.88	-6.91
-6.96	-7.00	-7.06	-7.15	-7.20	-7.24	-7.32	-7.42	-7.49
-7.52	-7.56	-7.62	-7.68	-7.75	-7.78	-7.82	-7.88	-7.95
-8.05	-8.09	-8.14						
6.03	6.00	3.35	2.40	1.93	1.18	.05	-.73	-.71
-.92	-.93	-1.00	-1.33	-1.65	-2.09	-2.61	-3.12	-3.80
-4.14	-4.43	-4.67	-4.89	-5.50	-5.57	-5.20	-4.98	-4.84
-4.76	-5.03	-4.85	-5.23	-5.11	-5.28	-5.41	-5.76	-5.98
-5.83	-5.93	-6.36	-6.13	-6.16	-6.70	-6.54	-6.42	-6.85
-6.63	-6.62	-6.70	-6.68	-6.70	-6.78	-6.85	-6.92	-6.93
-6.97	-7.03	-7.10	-7.22	-7.24	-7.28	-7.38	-7.49	-7.58
-7.58	-7.63	-7.73	-7.77	-7.85	-7.85	-7.90	-7.97	-8.01
-8.10	-8.14	-8.19						
5.78	5.00	3.61	2.28	1.43	.60	-.10	-.58	-.83
-.96	-1.06	-1.18	-1.45	-1.88	-2.33	-2.86	-3.38	-3.87
-4.26	-4.50	-4.68	-4.83	-4.94	-4.91	-4.83	-4.81	-4.81
-4.81	-4.83	-4.94	-5.05	-5.17	-5.30	-5.50	-5.66	-5.76
-5.82	-5.91	-6.06	-6.17	-6.22	-6.31	-6.39	-6.54	-6.64
-6.61	-6.52	-6.46	-6.46	-6.49	-6.55	-6.63	-6.70	-6.75
-6.80	-6.87	-6.93	-7.02	-7.08	-7.13	-7.23	-7.31	-7.37
-7.43	-7.48	-7.56	-7.61	-7.67	-7.72	-7.76	-7.81	-7.86
-7.92	-7.96	-7.99						
6.36	6.07	3.18	2.16	1.19	-.05	-.68	-.66	-.88
-1.08	-1.14	-1.24	-1.61	-1.91	-2.46	-3.01	-3.50	-3.85
-4.17	-4.42	-4.45	-4.30	-4.32	-4.02	-3.99	-4.02	-4.19
-4.33	-4.30	-4.44	-4.52	-4.65	-4.72	-5.01	-4.97	-5.24

-5.13	-5.22	-5.37	-5.41	-5.50	-5.64	-5.73	-5.99	-6.14
-6.08	-6.07	-6.13	-6.22	-6.25	-6.28	-6.40	-6.46	-6.56
-6.61	-6.69	-6.71	-6.82	-6.93	-6.97	-7.04	-7.11	-7.17
-7.27	-7.31	-7.35	-7.38	-7.49	-7.60	-7.63	-7.64	-7.69
-7.74	-7.80	-7.81						
5.79	5.10	3.41	1.88	.78	-.08	-.60	-.84	-1.05
-1.21	-1.32	-1.47	-1.78	-2.21	-2.68	-3.21	-3.63	-3.90
-4.08	-4.20	-4.22	-4.18	-4.09	-4.04	-4.03	-4.07	-4.20
-4.28	-4.31	-4.39	-4.50	-4.60	-4.68	-4.81	-4.93	-5.01
-5.10	-5.21	-5.32	-5.42	-5.51	-5.61	-5.72	-5.85	-5.95
-6.05	-6.12	-6.18	-6.25	-6.30	-6.39	-6.47	-6.54	-6.62
-6.68	-6.78	-6.86	-6.94	-7.00	-7.05	-7.16	-7.23	-7.28
-7.35	-7.41	-7.49	-7.54	-7.60	-7.66	-7.71	-7.75	-7.79
-7.84	-7.88	-7.91						
6.18	5.50	3.46	1.47	.05	-.68	-.82	-1.15	-1.38
-1.54	-1.57	-1.85	-2.14	-2.57	-3.06	-3.54	-3.87	-4.08
-4.06	-3.94	-3.78	-3.71	-3.69	-3.76	-3.83	-3.91	-4.03
-4.17	-4.24	-4.32	-4.43	-4.55	-4.63	-4.74	-4.82	-4.87
-4.96	-5.08	-5.22	-5.36	-5.46	-5.57	-5.68	-5.84	-5.91
-6.01	-6.14	-6.20	-6.28	-6.35	-6.47	-6.54	-6.62	-6.70
-6.79	-6.90	-7.04	-7.11	-7.14	-7.19	-7.28	-7.38	-7.43
-7.47	-7.54	-7.65	-7.69	-7.73	-7.78	-7.84	-7.94	-7.98
-8.02	-8.06	-8.10						
5.90	5.18	3.36	1.41	-.01	-.68	-.92	-1.21	-1.47
-1.60	-1.68	-1.91	-2.19	-2.61	-3.10	-3.54	-3.85	-4.01
-3.99	-3.87	-3.74	-3.69	-3.66	-3.72	-3.80	-3.86	-3.99
-4.11	-4.21	-4.29	-4.39	-4.51	-4.60	-4.69	-4.79	-4.85
-4.94	-5.05	-5.17	-5.31	-5.43	-5.55	-5.66	-5.81	-5.89
-5.99	-6.11	-6.19	-6.28	-6.35	-6.46	-6.54	-6.63	-6.71
-6.80	-6.90	-7.00	-7.09	-7.12	-7.17	-7.26	-7.35	-7.42
-7.47	-7.55	-7.64	-7.68	-7.73	-7.78	-7.84	-7.91	-7.94
-7.99	-8.04	-8.08						
5.84	5.00	3.04	1.10	-.40	-.87	-1.06	-1.30	-1.61
-1.80	-1.89	-1.98	-2.19	-2.66	-3.20	-3.59	-3.81	-3.86
-3.78	-3.68	-3.61	-3.58	-3.55	-3.61	-3.68	-3.77	-3.89
-3.98	-4.10	-4.18	-4.29	-4.40	-4.48	-4.59	-4.69	-4.76
-4.85	-4.96	-5.05	-5.21	-5.35	-5.44	-5.58	-5.74	-5.83
-5.92	-6.03	-6.15	-6.25	-6.33	-6.45	-6.54	-6.66	-6.74
-6.80	-6.86	-6.93	-7.01	-7.06	-7.11	-7.17	-7.26	-7.35
-7.42	-7.49	-7.58	-7.64	-7.69	-7.74	-7.77	-7.81	-7.84
-7.90	-7.96	-8.01						
6.07	5.19	2.91	.90	-.64	-1.00	-1.11	-1.34	-1.68
-1.90	-1.97	-2.03	-2.20	-2.69	-3.23	-3.63	-3.83	-3.84
-3.72	-3.61	-3.55	-3.51	-3.49	-3.56	-3.64	-3.73	-3.84
-3.94	-4.04	-4.14	-4.24	-4.35	-4.43	-4.56	-4.65	-4.71
-4.83	-4.94	-5.02	-5.18	-5.31	-5.41	-5.56	-5.71	-5.80
-5.89	-6.01	-6.14	-6.24	-6.32	-6.45	-6.55	-6.67	-6.75
-6.80	-6.85	-6.92	-7.00	-7.05	-7.10	-7.16	-7.24	-7.35
-7.43	-7.50	-7.58	-7.63	-7.70	-7.74	-7.76	-7.80	-7.82
-7.88	-7.95	-8.01						
5.76	4.69	2.54	.73	-.47	-1.01	-1.30	-1.58	-1.85
-2.08	-2.22	-2.24	-2.31	-2.70	-3.26	-3.66	-3.89	-3.90
-3.81	-3.69	-3.60	-3.54	-3.52	-3.55	-3.62	-3.70	-3.78
-3.86	-3.97	-4.06	-4.18	-4.30	-4.41	-4.51	-4.63	-4.71

-4.81	-4.94	-5.06	-5.19	-5.29	-5.38	-5.52	-5.66	-5.75
-5.85	-5.98	-6.10	-6.20	-6.27	-6.38	-6.47	-6.57	-6.65
-6.69	-6.77	-6.87	-6.96	-7.04	-7.12	-7.22	-7.32	-7.43
-7.51	-7.60	-7.68	-7.71	-7.75	-7.78	-7.81	-7.84	-7.88
-7.93	-7.97	-8.01						
6.82	5.62	2.01	.46	-.57	-1.22	-1.22	-1.78	-1.97
-2.22	-2.43	-2.39	-2.04	-2.61	-3.34	-3.72	-3.97	-3.95
-3.81	-3.71	-3.60	-3.53	-3.49	-3.53	-3.59	-3.68	-3.75
-3.79	-3.93	-4.00	-4.12	-4.26	-4.36	-4.46	-4.58	-4.67
-4.81	-4.94	-5.04	-5.15	-5.27	-5.39	-5.52	-5.59	-5.73
-5.83	-5.94	-6.06	-6.15	-6.22	-6.32	-6.43	-6.51	-6.59
-6.63	-6.69	-6.83	-6.94	-7.04	-7.12	-7.20	-7.37	-7.48
-7.56	-7.64	-7.73	-7.74	-7.77	-7.80	-7.82	-7.86	-7.89
-7.95	-7.99	-8.03						
5.43	4.20	2.18	.53	-.51	-1.09	-1.44	-1.70	-1.96
-2.19	-2.30	-2.30	-2.35	-2.72	-3.28	-3.74	-3.94	-3.95
-3.87	-3.77	-3.68	-3.59	-3.55	-3.56	-3.60	-3.67	-3.76
-3.83	-3.93	-4.02	-4.15	-4.26	-4.38	-4.49	-4.61	-4.69
-4.81	-4.95	-5.08	-5.18	-5.27	-5.39	-5.51	-5.62	-5.71
-5.83	-5.96	-6.06	-6.15	-6.24	-6.35	-6.43	-6.51	-6.62
-6.69	-6.78	-6.89	-7.00	-7.08	-7.16	-7.26	-7.36	-7.45
-7.51	-7.59	-7.67	-7.72	-7.75	-7.78	-7.81	-7.85	-7.90
-7.96	-7.99	-8.03						
6.04	5.48	1.68	.43	-.63	-1.29	-1.45	-1.79	-2.07
-2.30	-2.48	-2.37	-2.07	-2.61	-3.18	-3.86	-4.04	-4.02
-3.92	-3.84	-3.72	-3.60	-3.57	-3.57	-3.60	-3.63	-3.78
-3.83	-3.90	-4.03	-4.15	-4.26	-4.39	-4.45	-4.58	-4.72
-4.79	-4.91	-5.07	-5.12	-5.33	-5.41	-5.49	-5.64	-5.70
-5.83	-5.97	-6.05	-6.15	-6.28	-6.35	-6.43	-6.50	-6.63
-6.72	-6.80	-6.92	-7.06	-7.12	-7.20	-7.26	-7.37	-7.42
-7.48	-7.54	-7.61	-7.68	-7.74	-7.77	-7.79	-7.84	-7.87
-7.96	-8.01	-8.05						
5.26	3.97	2.07	.50	-.53	-1.16	-1.50	-1.76	-1.97
-2.08	-2.14	-2.16	-2.30	-2.79	-3.37	-3.78	-3.97	-4.00
-3.94	-3.85	-3.76	-3.64	-3.59	-3.59	-3.61	-3.66	-3.76
-3.83	-3.92	-4.02	-4.16	-4.26	-4.38	-4.49	-4.61	-4.70
-4.81	-4.96	-5.09	-5.18	-5.27	-5.40	-5.51	-5.61	-5.71
-5.85	-5.96	-6.06	-6.14	-6.24	-6.35	-6.43	-6.51	-6.63
-6.73	-6.83	-6.95	-7.08	-7.16	-7.24	-7.32	-7.40	-7.47
-7.52	-7.58	-7.66	-7.73	-7.78	-7.81	-7.84	-7.89	-7.96
-8.03	-8.07	-8.13						
5.86	4.34	2.02	.64	-.63	-1.29	-1.53	-1.84	-1.90
-1.68	-1.66	-1.80	-2.19	-2.98	-3.52	-3.86	-4.00	-4.04
-4.00	-3.91	-3.83	-3.71	-3.64	-3.61	-3.63	-3.67	-3.73
-3.82	-3.90	-4.04	-4.15	-4.26	-4.38	-4.48	-4.61	-4.72
-4.81	-4.96	-5.07	-5.18	-5.29	-5.39	-5.54	-5.64	-5.73
-5.86	-5.96	-6.07	-6.18	-6.26	-6.35	-6.43	-6.54	-6.64
-6.74	-6.87	-7.01	-7.19	-7.26	-7.31	-7.38	-7.49	-7.56
-7.59	-7.62	-7.69	-7.79	-7.87	-7.89	-7.92	-8.00	-8.10
-8.19	-8.22	-8.26						
5.51	4.17	2.15	.62	-.55	-1.23	-1.53	-1.79	-1.85
-1.71	-1.68	-1.81	-2.20	-2.98	-3.50	-3.82	-3.98	-4.02
-3.99	-3.91	-3.82	-3.71	-3.64	-3.61	-3.63	-3.68	-3.74
-3.82	-3.92	-4.03	-4.16	-4.26	-4.38	-4.48	-4.62	-4.71

-4.81	-4.96	-5.09	-5.18	-5.28	-5.39	-5.54	-5.62	-5.73
-5.86	-5.95	-6.07	-6.17	-6.25	-6.35	-6.44	-6.53	-6.63
-6.74	-6.88	-7.01	-7.16	-7.24	-7.30	-7.37	-7.47	-7.54
-7.58	-7.62	-7.69	-7.78	-7.85	-7.88	-7.91	-7.99	-8.09
-8.17	-8.21	-8.25						
5.05	4.02	2.27	.60	-.48	-1.16	-1.53	-1.71	-1.75
-1.72	-1.71	-1.85	-2.22	-2.89	-3.40	-3.74	-3.95	-3.99
-3.97	-3.89	-3.82	-3.70	-3.63	-3.61	-3.63	-3.68	-3.75
-3.81	-3.93	-4.03	-4.17	-4.27	-4.38	-4.49	-4.62	-4.71
-4.81	-4.96	-5.11	-5.19	-5.27	-5.39	-5.52	-5.62	-5.72
-5.84	-5.94	-6.06	-6.15	-6.24	-6.34	-6.43	-6.51	-6.62
-6.73	-6.85	-6.98	-7.09	-7.18	-7.24	-7.33	-7.41	-7.49
-7.53	-7.58	-7.66	-7.74	-7.82	-7.85	-7.89	-7.96	-8.05
-8.13	-8.15	-8.19						
5.10	4.11	2.40	.63	-.52	-1.21	-1.53	-1.64	-1.60
-1.54	-1.55	-1.74	-2.13	-2.74	-3.26	-3.66	-3.91	-3.97
-3.95	-3.89	-3.81	-3.71	-3.63	-3.61	-3.63	-3.68	-3.74
-3.80	-3.93	-4.02	-4.14	-4.27	-4.38	-4.49	-4.61	-4.72
-4.80	-4.94	-5.10	-5.19	-5.27	-5.39	-5.51	-5.62	-5.72
-5.84	-5.93	-6.03	-6.13	-6.24	-6.32	-6.41	-6.50	-6.61
-6.71	-6.80	-6.91	-7.01	-7.11	-7.17	-7.26	-7.34	-7.41
-7.47	-7.53	-7.62	-7.70	-7.78	-7.83	-7.87	-7.94	-8.02
-8.10	-8.11	-8.14						
5.52	4.36	2.42	.63	-.67	-1.27	-1.58	-1.64	-1.53
-1.42	-1.47	-1.69	-2.10	-2.62	-3.13	-3.64	-3.90	-3.96
-3.94	-3.87	-3.80	-3.70	-3.62	-3.60	-3.62	-3.66	-3.73
-3.79	-3.91	-4.02	-4.12	-4.26	-4.39	-4.47	-4.60	-4.72
-4.81	-4.94	-5.08	-5.19	-5.28	-5.38	-5.52	-5.61	-5.71
-5.84	-5.93	-6.01	-6.13	-6.24	-6.32	-6.39	-6.49	-6.61
-6.69	-6.76	-6.84	-6.95	-7.05	-7.13	-7.22	-7.28	-7.34
-7.42	-7.50	-7.59	-7.66	-7.74	-7.81	-7.86	-7.91	-7.97
-8.04	-8.07	-8.10						
6.37	4.91	2.33	.64	-.85	-1.35	-1.63	-1.67	-1.52
-1.32	-1.43	-1.61	-2.11	-2.56	-3.09	-3.66	-3.92	-3.97
-3.94	-3.86	-3.81	-3.69	-3.61	-3.60	-3.60	-3.65	-3.72
-3.80	-3.88	-4.02	-4.11	-4.26	-4.40	-4.45	-4.60	-4.72
-4.82	-4.95	-5.07	-5.17	-5.30	-5.37	-5.51	-5.61	-5.69
-5.81	-5.94	-6.00	-6.14	-6.24	-6.31	-6.39	-6.48	-6.60
-6.69	-6.74	-6.80	-6.94	-7.03	-7.10	-7.22	-7.25	-7.31
-7.41	-7.49	-7.59	-7.65	-7.74	-7.81	-7.86	-7.89	-7.95
-8.02	-8.07	-8.10						
5.37	4.29	2.53	.81	-.47	-1.15	-1.45	-1.50	-1.44
-1.38	-1.45	-1.68	-2.05	-2.58	-3.12	-3.59	-3.85	-3.93
-3.92	-3.86	-3.79	-3.71	-3.64	-3.61	-3.62	-3.67	-3.72
-3.80	-3.92	-4.02	-4.12	-4.27	-4.39	-4.48	-4.60	-4.72
-4.80	-4.93	-5.08	-5.19	-5.28	-5.38	-5.51	-5.61	-5.70
-5.82	-5.92	-6.00	-6.11	-6.22	-6.31	-6.38	-6.47	-6.57
-6.65	-6.72	-6.80	-6.91	-7.01	-7.09	-7.18	-7.25	-7.32
-7.39	-7.47	-7.57	-7.65	-7.72	-7.78	-7.83	-7.87	-7.92
-8.00	-8.03	-8.06						
5.30	4.26	2.69	1.14	-.12	-.90	-1.21	-1.27	-1.28
-1.31	-1.42	-1.65	-1.98	-2.59	-3.18	-3.55	-3.80	-3.88
-3.90	-3.86	-3.79	-3.72	-3.66	-3.62	-3.63	-3.68	-3.72
-3.81	-3.94	-4.03	-4.13	-4.28	-4.40	-4.48	-4.59	-4.73

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  -4.81   -4.93   -5.08   -5.20   -5.28   -5.38   -5.50   -5.60   -5.68
  -5.80   -5.89   -5.99   -6.09   -6.21   -6.29   -6.36   -6.44   -6.52
  -6.59   -6.67   -6.75   -6.88   -6.98   -7.05   -7.14   -7.22   -7.31
  -7.37   -7.44   -7.54   -7.63   -7.69   -7.73   -7.77   -7.81   -7.88
  -7.95   -7.97   -8.00
   5.52    4.40    2.91    1.48     .14    -.70    -.99   -1.05   -1.12
  -1.22   -1.36   -1.59   -1.92   -2.55   -3.22   -3.55   -3.75   -3.86
  -3.89   -3.86   -3.80   -3.74   -3.68   -3.63   -3.63   -3.67   -3.71
  -3.81   -3.95   -4.03   -4.12   -4.27   -4.39   -4.47   -4.58   -4.72
  -4.81   -4.92   -5.07   -5.19   -5.27   -5.39   -5.50   -5.60   -5.68
  -5.78   -5.89   -5.99   -6.09   -6.19   -6.28   -6.36   -6.42   -6.49
  -6.54   -6.61   -6.69   -6.83   -6.94   -7.02   -7.11   -7.20   -7.29
  -7.35   -7.41   -7.52   -7.60   -7.64   -7.68   -7.71   -7.76   -7.83
  -7.90   -7.93   -7.96
   5.85    4.97    3.06    1.67     .27    -.79    -.89    -.87   -1.05
  -1.17   -1.30   -1.50   -1.95   -2.57   -3.19   -3.55   -3.76   -3.86
  -3.91   -3.87   -3.81   -3.75   -3.67   -3.61   -3.63   -3.67   -3.72
  -3.79   -3.93   -4.02   -4.11   -4.26   -4.37   -4.46   -4.59   -4.69
  -4.80   -4.93   -5.05   -5.18   -5.26   -5.39   -5.51   -5.60   -5.69
  -5.80   -5.89   -6.00   -6.11   -6.19   -6.28   -6.36   -6.41   -6.48
  -6.53   -6.56   -6.67   -6.81   -6.94   -7.00   -7.08   -7.19   -7.28
  -7.35   -7.41   -7.50   -7.59   -7.62   -7.65   -7.67   -7.74   -7.80
  -7.88   -7.92   -7.95
WAVCOND    2.00    12.0   20.00
WAVCOND    1.50     8.0  -35.00
PLOTREC
```

APPENDIX 5-C: INPUT DATA SET FOR HOMER SPIT, ALASKA

```
GENSPECS        HOMER SPIT, ALASKA EXAMPLE                           ENGLISH
GRIDSPEC          ENGLISH       96       83    416.7    833.3
WAVCOND     8.00     10.0   -45.00
PRWINDOW       1       96        1       83    DAHB
BATHSPEC    FEET                                  YX (10F8.2)
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
```

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.18
-0.36	-0.66	-0.90	-1.38	-2.04	-1.92	-1.02	-0.78	-1.08	-1.20
-1.20	-0.78	-0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.18
-0.48	-0.84	-1.20	-1.68	-2.10	-1.92	-1.20	-0.96	-1.44	-1.62
-1.38	-0.96	-0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.18
-0.36	-1.20	-2.40	-3.06	-3.06	-3.00	-3.00	-3.06	-3.18	-3.24
-3.24	-2.94	-2.64	-2.22	-1.86	-1.38	-0.66	-0.36	-0.36	-0.24
-0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	-0.36	-1.02	-1.50	-1.86	-1.98	-1.80	1.50
-1.20	-0.78	-0.24	0.00	0.00	0.00	0.00	-0.42	-1.26	-1.68
-1.68	-2.34	-3.30	-4.02	-4.20	-4.68	-5.46	-5.76	-5.46	-5.28
-5.22	-5.22	-5.22	-4.80	-4.08	-3.12	-2.22	-1.56	-1.38	-0.96
-0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.06
-0.24	-0.48	-0.84	-1.62	-2.64	-3.48	-3.72	-3.60	-3.24	-2.64
-2.16	-1.56	-1.26	-0.78	-0.24	0.00	0.00	-1.08	-2.94	3.96
-3.78	-4.44	-5.82	-6.30	-5.76	-6.00	-6.72	-7.02	-6.78	-6.78
-7.20	-7.38	-7.38	-6.60	-5.28	-4.20	-3.72	-3.24	-3.00	-2.34
-1.50	-0.78	-0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-0.78	-0.48	-0.18	0.00	0.00	-0.36	-1.02	-1.44	-1.62	-1.80
-1.86	-2.22	-2.58	-3.30	-4.08	-4.74	-5.04	-4.80	-4.08	-3.42
-3.06	-2.58	-2.04	-1.62	-1.50	-1.20	-0.84	-1.86	-3.66	-5.58
-7.14	-8.16	-8.16	-7.98	-7.44	-7.62	-8.64	-9.18	-9.06	-9.24

-9.54	-9.42	-8.76	-7.68	-6.54	-5.58	-5.10	-4.86	-4.98	-4.32
-3.12	-1.80	-0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-1.80	-1.56	-1.68	-1.80	-1.98	-2.46	-3.00	-3.48	-3.60	-3.48
-3.18	-3.42	-4.20	-4.98	-5.58	-6.18	-6.48	-6.12	-5.10	-4.62
-4.86	-4.32	-3.12	-2.58	-2.64	-2.76	-2.88	-4.14	-6.24	-8.58
-10.08	-10.50	-9.42	-8.76	-8.82	-9.54	-10.74	-11.46	-11.46	-11.58
-11.76	-11.10	-9.84	-8.76	-8.28	-7.44	-6.60	-6.18	-6.24	-5.58
-4.44	-3.00	-2.04	-1.02	-0.36	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-3.42	-3.42	-3.78	-4.02	-3.96	-4.26	-4.74	-5.10	-5.16	-4.86
-4.32	-4.68	-5.76	-6.48	-6.54	-6.96	-7.56	-7.62	-7.44	-7.32
-7.56	-6.72	-5.04	-4.02	-4.02	-4.62	-5.64	-7.14	-8.34	-9.90
-11.10	-11.22	-10.50	-10.26	-10.68	-11.46	-12.18	-12.78	-12.96	-13.08
-13.20	-12.48	-11.10	-9.96	-9.36	-8.76	-8.52	-8.04	-7.56	-6.78
-6.06	-4.98	-4.02	-2.52	-0.90	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-5.10	-5.46	-5.88	-5.88	-5.46	-5.46	-5.82	-6.18	-6.54	-6.36
-5.82	-6.06	-6.96	-7.26	-6.84	-7.20	-8.16	-9.00	-9.42	-9.96
-10.44	-9.48	-7.38	-6.00	-5.64	-6.12	-7.14	-8.04	-8.40	-9.60
-11.10	-11.82	-11.64	-11.88	-12.60	-13.20	-13.38	-13.80	-14.22	-14.28
-13.98	-13.14	-12.12	-11.22	-10.92	-10.62	-10.38	-9.84	-9.24	-8.34
-7.44	-6.42	-5.70	-4.14	-2.46	-1.38	-1.38	-1.02	-0.36	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-6.54	-6.90	-7.32	-7.56	-7.68	-7.74	-7.80	-7.80	-7.56	-7.32
-6.90	-7.08	-7.74	-7.92	-7.50	-7.68	-8.28	-8.82	-9.00	-10.02
-11.52	-11.34	-9.90	-8.58	-8.04	-7.92	-8.22	-8.40	-8.16	-9.06
-10.68	-11.58	-11.40	-12.00	-13.14	-13.86	-14.04	-14.64	-15.54	-15.60
-14.88	-14.04	-13.44	-12.78	-12.24	-12.00	-12.12	-11.76	-11.04	-9.96
-8.88	-7.98	-7.62	-6.48	-4.98	-4.02	-3.84	-2.76	-1.02	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-9.00	-8.64	-8.04	-8.28	-9.18	-9.66	-9.66	-9.24	-8.58	-7.98
-7.68	-7.68	-7.92	-8.22	-8.64	-8.70	-8.46	-8.22	-7.92	-9.06
-11.28	-12.42	-12.36	-11.46	-10.08	-9.36	-9.36	-8.94	-8.22	-8.70
-10.14	-10.98	-10.86	-11.52	-12.72	-13.80	-14.40	-15.30	-16.20	-16.02
-14.76	-13.98	-14.16	-13.92	-13.62	-13.62	-13.98	-13.62	-12.66	-11.40
-10.32	-9.36	-8.76	-7.98	-7.50	-6.66	-5.88	-4.44	-2.76	-1.26
-0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-12.00	-11.52	-10.26	-9.96	-10.74	-11.22	-11.22	-10.80	-10.14	-9.48
-9.06	-8.76	-8.58	-8.88	-9.54	-9.60	-9.06	-8.52	-8.10	-8.58
-9.48	-10.80	-11.88	-11.34	-9.66	-8.52	-8.34	-8.10	-7.98	-8.64
-9.96	-10.98	-11.28	-12.00	-12.72	-13.62	-14.22	-15.18	-15.96	-15.78

-14.88	-14.46	-14.82	-14.88	-14.58	-14.82	-15.60	-15.42	-14.52	-13.20
-11.94	-10.80	-10.14	-9.60	-9.24	-8.58	-7.86	-6.12	-3.90	-1.98
-1.02	-0.24	-0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-14.58	-14.22	-13.38	-12.84	-12.66	-12.96	-13.44	-13.26	-12.60	-11.82
-11.28	-10.86	-10.80	-10.86	-11.04	-10.74	-9.84	-8.94	-8.16	-7.92
-8.22	-8.82	-9.30	-9.06	-8.10	-7.38	-7.26	-7.44	-7.86	-9.06
-10.56	-11.82	-12.36	-12.84	-13.02	-13.44	-13.80	-14.04	-13.86	-13.92
-14.22	-14.76	-15.54	-15.60	-15.06	-15.30	-16.20	-16.50	-16.02	-15.12
-14.28	-13.14	-12.06	-11.16	-10.62	-9.96	-9.42	-7.20	-3.96	-1.74
-1.26	-0.66	-0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-16.86	-16.44	-15.60	-14.82	-14.46	-14.64	-15.24	-15.36	-14.88	-14.22
-13.68	-13.38	-13.38	-13.08	-12.60	-11.76	-10.86	-9.48	-8.16	-7.68
-8.10	-8.34	-8.16	-7.80	-7.44	-7.14	-6.96	-7.38	-8.22	-9.72
-11.34	-12.78	-13.44	-13.68	-13.38	-13.56	-14.16	-13.80	-12.66	-12.48
-13.32	-14.52	-15.78	-16.20	-15.66	-15.78	-16.38	-16.62	-16.38	-16.20
-16.32	-15.42	-13.92	-12.60	-11.88	-11.16	-10.62	-8.40	-5.40	-3.00
-2.04	-1.14	-0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-17.94	-17.76	-16.86	-16.14	-15.84	-16.02	-16.56	-16.98	-17.22	-16.80
-15.90	-15.06	-14.40	-13.62	-13.02	-12.18	-11.58	-10.20	-8.64	-7.80
-7.92	-7.98	-7.86	-7.38	-6.60	-6.30	-6.66	-7.38	-8.40	-9.90
-11.34	-13.20	-14.82	-15.06	-13.86	-13.86	-15.00	-15.12	-14.28	-13.92
-14.22	-15.12	-16.14	-16.56	-16.20	-16.08	-16.32	-16.38	-16.26	-16.68
-17.58	-17.52	-16.74	-15.24	-13.62	-12.18	-11.28	-9.60	-7.74	-5.34
-3.30	-1.56	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-18.54	-18.60	-18.12	-17.64	-17.40	-17.64	-18.36	-18.90	-19.14	-18.72
-17.82	-16.20	-14.46	-13.44	-13.62	-13.14	-12.24	-10.86	-9.36	-8.22
-7.74	-7.62	-7.98	-7.38	-6.12	-5.82	-6.48	-7.50	-8.40	-9.84
-11.16	-13.38	-15.72	-16.32	-15.06	-14.88	-15.90	-16.38	-16.20	-15.96
-15.78	-16.02	-16.50	-16.74	-16.62	-16.44	-16.26	-16.20	-16.20	-17.04
-18.42	-18.96	-18.36	-16.92	-15.30	-13.38	-12.00	-10.38	-9.24	-7.14
-5.10	-3.12	-2.04	-1.26	-1.08	-0.78	-0.24	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-19.56	-19.98	-20.22	-20.16	-19.86	-20.04	-20.52	-20.64	-20.28	-19.62
-18.84	-17.16	-15.36	-14.64	-15.36	-14.76	-13.02	-11.40	-10.62	-9.36
-8.22	-7.86	-8.40	-8.16	-7.32	-6.90	-6.96	-7.44	-7.98	-9.90
-12.78	-15.36	-16.74	-17.16	-16.26	-16.02	-16.50	-16.80	-16.80	-16.74
-16.62	-16.62	-16.74	-16.80	-16.80	-16.62	-16.38	-16.20	-16.20	-17.28
-19.08	-19.92	-19.62	-18.42	-16.92	-14.88	-12.90	-11.22	-10.50	-9.06
-7.50	-5.40	-3.48	-2.34	-2.22	-1.56	-0.60	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-19.86	-20.46	-21.18	-21.66	-21.90	-22.02	-21.96	-21.60	-21.06	-20.22
-19.44	-18.06	-16.56	-16.02	-16.50	-15.48	-13.32	-11.64	-11.16	-10.20
-9.42	-9.00	-9.18	-9.36	-9.48	-9.06	-8.28	-7.86	-7.80	-10.62
-15.42	-18.30	-18.24	-17.82	-17.04	-16.62	-16.74	-16.98	-17.28	-17.28

-16.98	-16.80	-16.80	-16.80	-16.80	-16.44	-15.84	-15.78	-16.26	-17.64
-19.32	-20.64	-21.18	-20.40	-18.84	-17.10	-16.14	-14.40	-12.48	-10.68
-9.30	-7.14	-5.10	-3.42	-2.76	-1.74	-0.66	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-20.28	-20.70	-21.00	-21.84	-22.92	-23.22	-22.80	-22.20	-21.66	-20.82
-20.04	-18.78	-17.64	-16.80	-16.56	-15.48	-13.98	-12.54	-11.64	-10.98
-10.80	-10.44	-10.08	-10.26	-10.80	-10.74	-10.14	-9.66	-9.60	-12.12
-16.14	-18.78	-18.96	-18.54	-17.88	-17.46	-17.46	-17.64	-17.82	-17.82
-17.64	-17.22	-16.74	-16.74	-17.22	-16.92	-15.90	-15.66	-16.14	-17.64
-19.56	-21.18	-21.78	-21.48	-20.34	-19.02	-17.94	-16.02	-13.98	-11.88
-10.50	-8.70	-7.14	-5.16	-3.42	-1.74	-0.66	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-21.36	-21.96	-22.44	-23.28	-24.12	-24.18	-23.28	-22.62	-22.44	-21.60
-20.46	-19.20	-18.30	-17.40	-16.86	-15.96	-15.06	-13.74	-12.48	-11.76
-11.76	-11.40	-10.86	-10.86	-11.40	-11.46	-11.04	-10.74	-10.56	-12.30
-15.18	-17.76	-19.14	-19.56	-19.02	-18.78	-18.96	-18.78	-18.24	-18.24
-18.78	-18.78	-18.48	-18.42	-18.54	-17.94	-16.68	-16.08	-16.38	-17.88
-20.04	-21.66	-22.20	-21.96	-21.00	-19.56	-18.30	-16.50	-14.88	-13.20
-12.24	-10.62	-9.12	-6.96	-4.98	-3.00	-1.74	-0.78	-0.24	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-22.44	-23.70	-25.08	-25.38	-24.30	-23.52	-23.10	-22.74	-22.56	-21.96
-21.30	-20.34	-19.50	-18.54	-17.64	-16.62	-15.84	-14.52	-13.14	-12.36
-12.36	-12.12	-11.70	-11.82	-12.36	-12.66	-12.84	-12.66	-12.42	-13.56
-15.54	-17.94	-19.68	-20.22	-19.38	-19.26	-20.04	-20.16	-19.68	-19.68
-20.16	-20.76	-21.24	-21.00	-20.04	-18.90	-17.88	-17.10	-16.86	-18.12
-20.28	-21.96	-22.44	-22.20	-21.30	-20.22	-19.50	-18.12	-16.68	-15.00
-13.68	-12.06	-10.56	-8.70	-7.14	-4.92	-2.70	-1.20	-0.90	-0.48
-0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-25.14	-26.28	-26.94	-26.34	-24.60	-23.40	-23.22	-22.80	-22.20	-22.02
-22.44	-21.72	-20.04	-18.60	-17.88	-16.92	-16.08	-14.88	-13.68	-13.08
-13.44	-13.38	-12.90	-13.02	-13.56	-14.28	-15.00	-15.18	-14.70	-15.48
-17.10	-18.96	-20.46	-20.76	-19.86	-19.86	-20.76	-21.36	-21.42	-21.42
-21.36	-21.66	-22.14	-21.90	-21.06	-20.16	-19.68	-19.44	-19.74	-20.34
-20.76	-21.66	-22.38	-22.38	-21.78	-20.94	-20.22	-19.38	-18.90	-17.94
-17.16	-15.18	-12.66	-10.38	-9.06	-6.48	-3.60	-1.86	-1.86	-1.38
-0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-29.16	-29.70	-28.56	-27.36	-26.58	-25.56	-24.60	-23.40	-22.26	-21.60
-21.36	-20.40	-18.90	-17.82	-17.82	-17.34	-16.68	-15.72	-14.82	-14.46
-14.82	-14.94	-14.70	-14.82	-15.18	-15.90	-16.74	-16.86	-16.32	-16.86
-18.12	-19.86	-21.36	-21.78	-21.00	-20.70	-21.00	-21.36	-21.42	-21.54
-21.60	-21.78	-22.02	-21.78	-21.06	-20.76	-21.00	-21.48	-22.14	-22.02
-21.18	-21.24	-22.20	-22.62	-22.44	-21.72	-20.70	-19.98	-19.62	-19.38
-19.26	-17.64	-15.24	-12.60	-10.74	-8.22	-5.94	-4.26	-3.90	-2.76
-1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-31.44	-31.50	-30.12	-29.04	-28.80	-27.72	-26.22	-24.30	-22.62	-21.12
-20.28	-19.20	-18.18	-17.82	-18.24	-18.24	-17.76	-17.22	-16.92	-16.26
-15.36	-15.24	-15.96	-16.38	-16.44	-17.10	-18.12	-18.42	-18.06	-18.30
-19.02	-20.46	-21.90	-22.56	-22.26	-21.78	-21.24	-20.94	-20.76	-20.82

-21.12	-21.54	-21.96	-21.72	-20.88	-20.88	-21.78	-22.44	-22.62	-22.08
-20.82	-20.70	-21.78	-22.56	-22.74	-22.20	-21.30	-20.22	-19.38	-19.20
-19.86	-18.96	-16.92	-14.46	-12.48	-10.38	-9.18	-7.56	-6.00	-3.72
-1.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-32.64	-32.52	-32.28	-31.38	-30.18	-28.56	-26.82	-24.54	-22.50	-20.40
-18.96	-18.00	-18.00	-18.30	-19.02	-19.14	-18.60	-18.48	-18.84	-18.36
-17.40	-17.16	-17.76	-18.06	-17.88	-18.24	-18.78	-19.20	-19.26	-19.62
-20.16	-21.24	-22.38	-23.04	-22.86	-22.56	-22.26	-21.78	-21.30	-21.06
-21.00	-21.36	-21.84	-21.78	-21.18	-21.12	-21.72	-22.32	-22.62	-21.90
-20.40	-20.04	-20.94	-21.84	-22.44	-22.38	-21.78	-21.12	-20.88	-20.76
-20.82	-19.86	-18.06	-15.78	-14.10	-12.24	-10.98	-9.30	-7.98	-5.94
-4.20	-2.28	-0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-35.04	-34.68	-34.62	-33.36	-31.14	-28.68	-26.64	-24.24	-22.26	-20.28
-19.26	-18.60	-18.60	-19.02	-19.50	-19.56	-19.20	-19.20	-19.56	-19.62
-19.44	-19.38	-19.44	-19.56	-19.62	-19.62	-19.56	-19.80	-20.22	-20.82
-21.36	-22.08	-22.68	-22.98	-22.86	-22.86	-23.04	-22.80	-22.26	-21.60
-21.00	-21.36	-22.56	-22.74	-21.84	-21.24	-21.00	-21.42	-22.32	-21.78
-20.22	-19.86	-21.00	-21.84	-21.96	-22.14	-22.26	-22.26	-22.20	-22.02
-21.84	-20.70	-19.08	-17.10	-15.48	-13.56	-12.12	-10.62	-9.66	-8.10
-6.42	-3.90	-1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00							
-37.50	-36.96	-36.18	-34.14	-31.56	-28.62	-26.28	-23.94	-22.56	-21.18
-20.28	-19.80	-19.86	-19.86	-19.80	-19.68	-19.50	-19.56	-19.80	-20.04
-20.10	-20.16	-20.16	-20.22	-20.34	-20.40	-20.46	-20.58	-20.70	-21.18
-21.84	-22.38	-22.62	-22.62	-22.32	-22.62	-23.58	-23.52	-22.44	-21.78
-21.84	-22.44	-23.34	-23.52	-22.80	-22.02	-21.66	-21.66	-21.90	-21.66
-21.06	-21.12	-21.96	-22.20	-21.60	-21.48	-21.90	-22.20	-22.44	-22.56
-22.56	-21.72	-20.46	-18.36	-16.26	-14.16	-12.84	-11.52	-10.80	-8.94
-6.72	-4.62	-3.54	-2.04	-0.66	-0.18	-0.48	-0.48	-0.18	0.00
0.00	0.00	0.00							
-38.58	-37.80	-36.90	-35.28	-33.78	-30.36	-26.28	-23.58	-23.22	-22.14
-20.88	-20.22	-20.34	-20.40	-20.46	-20.34	-20.16	-20.10	-20.16	-20.40
-20.64	-20.64	-20.46	-20.40	-20.40	-20.76	-21.36	-21.36	-20.82	-21.06
-22.02	-22.98	-23.76	-23.40	-22.02	-22.44	-24.48	-25.14	-24.48	-24.12
-24.36	-24.60	-24.60	-24.42	-24.06	-23.40	-22.62	-21.96	-21.54	-21.36
-21.54	-22.02	-22.74	-22.62	-21.84	-21.18	-20.76	-21.24	-22.44	-23.04
-22.86	-22.14	-21.06	-19.44	-18.00	-16.14	-14.58	-13.38	-12.84	-10.92
-8.34	-6.42	-5.82	-4.56	-3.30	-2.28	-1.98	-1.38	-0.48	0.00
0.00	0.00	0.00							
-38.64	-38.10	-37.62	-36.78	-36.00	-33.12	-29.52	-26.28	-24.60	-22.98
-21.84	-20.88	-20.58	-20.64	-21.06	-21.18	-20.88	-20.76	-20.76	-20.88
-21.18	-21.06	-20.64	-20.22	-19.92	-20.40	-21.54	-21.90	-21.42	-21.60
-22.32	-23.52	-24.78	-24.90	-24.00	-24.42	-26.04	-27.24	-27.66	-27.30
-26.28	-25.74	-25.62	-25.38	-25.08	-24.78	-24.72	-23.88	-22.68	-22.08
-22.20	-22.68	-23.34	-23.16	-22.20	-21.30	-20.82	-21.36	-22.86	-23.22
-22.26	-21.36	-20.82	-19.92	-19.08	-17.70	-16.26	-14.94	-14.22	-12.72
-11.22	-9.36	-7.86	-6.36	-5.22	-4.02	-3.24	-1.98	-0.72	0.00
0.00	-0.18	-0.48							
-37.02	-36.96	-38.22	-38.34	-37.50	-35.10	-31.92	-28.50	-26.16	-24.00
-22.92	-21.96	-21.42	-21.24	-21.42	-21.54	-21.42	-21.30	-21.24	-21.24
-21.36	-21.12	-20.70	-19.98	-19.26	-19.80	-21.30	-22.20	-22.26	-22.44
-22.62	-23.70	-25.20	-26.16	-26.22	-26.94	-28.20	-28.86	-28.50	-27.90

-27.30	-26.58	-26.04	-25.74	-25.62	-25.80	-26.16	-25.38	-23.82	-22.62
-22.32	-22.80	-24.00	-24.00	-22.92	-22.14	-21.84	-22.14	-22.86	-22.92
-22.44	-21.60	-20.82	-19.74	-18.60	-17.28	-16.26	-15.12	-14.28	-13.74
-13.74	-12.60	-10.92	-8.52	-6.12	-4.50	-4.02	-3.12	-2.28	-1.98
-2.46	-2.88	-3.06							
-36.66	-36.12	-36.90	-37.68	-38.04	-36.30	-33.48	-30.12	-27.48	-25.38
-24.66	-23.64	-22.80	-22.14	-21.90	-21.78	-21.78	-21.66	-21.54	-21.36
-21.24	-20.94	-20.58	-19.80	-18.84	-19.68	-22.14	-23.70	-24.00	-24.24
-24.42	-25.08	-25.86	-26.76	-27.36	-28.32	-29.34	-29.70	-29.28	-28.62
-27.96	-27.12	-26.28	-25.74	-25.56	-25.62	-25.92	-25.14	-23.70	-22.32
-21.42	-22.08	-24.06	-24.54	-23.46	-22.56	-22.14	-22.14	-22.56	-22.80
-22.80	-22.14	-21.06	-19.50	-18.00	-16.56	-15.78	-14.82	-14.22	-14.28
-15.18	-14.58	-12.84	-10.68	-9.24	-7.44	-6.00	-4.86	-4.32	-4.26
-4.56	-4.80	-4.80							
-37.86	-36.42	-35.94	-36.48	-37.92	-37.44	-35.34	-32.22	-29.22	-26.82
-25.80	-24.54	-23.46	-22.62	-22.26	-22.08	-22.08	-21.96	-21.72	-21.54
-21.42	-21.18	-20.88	-19.98	-18.72	-19.80	-22.80	-25.38	-26.82	-27.24
-26.46	-26.58	-27.36	-28.14	-28.80	-29.82	-30.78	-31.02	-30.36	-29.40
-28.50	-27.42	-26.64	-25.80	-25.20	-25.14	-25.56	-24.96	-23.64	-22.56
-22.32	-22.92	-24.06	-24.30	-23.40	-22.44	-21.96	-21.66	-21.72	-21.84
-22.02	-21.30	-19.86	-18.30	-17.22	-16.02	-15.42	-14.76	-14.40	-14.70
-15.60	-15.24	-13.68	-11.82	-10.26	-9.06	-8.76	-8.28	-8.28	-7.86
-7.20	-6.84	-6.84							
-41.46	-39.54	-36.42	-35.88	-37.86	-38.16	-36.96	-34.26	-31.08	-27.90
-25.50	-23.70	-22.98	-22.32	-22.14	-22.14	-22.26	-22.14	-21.78	-21.66
-21.84	-21.78	-21.48	-20.70	-19.68	-20.58	-23.04	-25.86	-27.84	-28.86
-28.62	-28.74	-29.16	-29.70	-30.06	-31.08	-32.34	-32.40	-31.32	-29.76
-28.14	-27.12	-27.12	-26.76	-26.28	-26.04	-26.04	-25.14	-23.46	-22.80
-23.40	-23.88	-24.12	-23.88	-23.22	-22.62	-22.44	-21.96	-21.36	-20.76
-20.16	-19.38	-18.54	-17.28	-15.96	-15.06	-14.82	-14.58	-14.46	-14.64
-14.94	-14.70	-14.04	-12.96	-12.30	-11.64	-11.28	-11.28	-11.40	-11.46
-11.70	-11.76	-11.76							
-46.68	-44.94	-39.48	-37.14	-38.64	-38.64	-36.90	-33.90	-30.66	-27.54
-25.86	-23.94	-22.62	-21.84	-21.78	-22.80	-24.78	-24.96	-23.22	-22.44
-22.68	-22.44	-21.72	-21.12	-20.94	-21.90	-23.76	-25.98	-27.72	-29.16
-29.64	-30.24	-30.72	-31.08	-31.14	-31.98	-33.18	-33.42	-32.64	-30.66
-28.20	-27.06	-27.60	-27.66	-27.24	-27.18	-27.54	-26.04	-23.22	-22.20
-23.34	-23.82	-23.52	-22.92	-22.26	-22.02	-22.32	-22.14	-21.66	-20.52
-19.08	-18.18	-18.06	-16.98	-15.42	-14.34	-14.16	-14.10	-14.10	-14.16
-14.34	-14.22	-13.98	-14.22	-14.94	-15.12	-14.82	-14.52	-14.34	-15.18
-16.74	-17.64	-17.64							
-49.08	-47.16	-42.54	-39.54	-39.36	-38.04	-36.06	-32.58	-28.92	-26.88
-27.18	-25.80	-23.40	-21.96	-22.14	-23.22	-24.78	-24.96	-23.76	-23.16
-23.52	-23.22	-22.44	-22.14	-22.56	-23.46	-24.54	-26.34	-28.26	-29.88
-30.72	-31.56	-32.10	-32.40	-32.40	-32.88	-33.72	-34.02	-33.78	-31.80
-28.80	-26.94	-26.76	-26.58	-26.46	-27.06	-28.14	-26.64	-23.16	-21.48
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-18.54	-17.28	-17.16	-16.20	-14.70	-13.80	-13.80	-13.80	-13.80	-13.98
-14.22	-14.22	-13.98	-14.22	-14.88	-15.78	-16.62	-18.00	-19.56	-24.60
-31.44	-35.58	-35.58							
-48.78	-46.38	-43.62	-41.28	-40.20	-38.16	-36.12	-33.18	-30.48	-29.28
-30.06	-28.20	-24.72	-22.98	-23.70	-24.12	-24.00	-23.70	-23.46	-23.52
-24.00	-24.24	-24.12	-24.00	-24.06	-24.36	-24.84	-26.76	-29.22	-31.50
-32.58	-33.66	-34.26	-34.26	-33.72	-33.30	-33.36	-33.06	-32.58	-30.66

-28.02	-26.28	-25.92	-25.68	-25.62	-26.10	-27.12	-26.52	-24.42	-22.62
-21.90	-21.60	-21.96	-21.72	-20.82	-20.22	-20.22	-20.52	-21.18	-20.70
-19.14	-17.70	-16.98	-15.48	-13.92	-13.44	-14.16	-14.58	-14.46	-14.22
-13.98	-14.16	-14.58	-14.76	-14.58	-15.96	-18.30	-21.48	-24.12	-35.82
-51.12	-61.20	-61.20							
-47.64	-45.30	-43.74	-42.36	-41.58	-40.02	-38.10	-36.12	-34.80	-33.42
-32.88	-30.36	-26.88	-25.38	-26.46	-26.64	-26.10	-25.26	-24.60	-24.72
-25.50	-26.34	-26.64	-26.10	-25.02	-24.78	-25.44	-27.72	-30.54	-32.88
-33.84	-35.04	-36.00	-35.76	-34.44	-33.24	-32.76	-31.74	-30.66	-28.74
-26.82	-25.80	-26.16	-26.04	-25.56	-25.56	-26.04	-25.98	-25.44	-23.94
-22.14	-21.42	-22.02	-22.14	-21.66	-20.94	-20.22	-20.16	-20.76	-20.76
-20.16	-18.96	-17.64	-15.60	-13.80	-13.38	-14.58	-15.12	-14.76	-14.34
-13.86	-14.28	-15.36	-16.20	-16.20	-18.84	-22.56	-27.36	-30.42	-47.22
-68.82	-83.28	-83.28							
-47.22	-44.82	-43.80	-42.42	-41.64	-40.14	-38.88	-36.96	-35.40	-33.96
-32.94	-30.36	-27.54	-26.16	-26.94	-27.06	-26.34	-25.44	-24.84	-25.02
-26.04	-26.88	-27.18	-26.58	-25.14	-24.84	-25.74	-28.02	-30.72	-33.06
-33.96	-35.16	-36.00	-35.76	-34.44	-33.24	-32.76	-31.74	-30.66	-28.74
-26.70	-25.74	-26.16	-26.04	-25.56	-25.56	-26.04	-25.98	-25.20	-23.70
-22.08	-21.42	-22.14	-22.20	-21.60	-20.82	-20.22	-20.16	-20.58	-20.58
-20.16	-18.96	-17.64	-15.60	-13.80	-13.38	-14.52	-15.00	-14.58	-14.16
-14.04	-14.46	-15.30	-16.14	-16.86	-19.62	-23.46	-28.32	-32.52	-49.44
-72.36	-86.88	-86.88							
-46.20	-44.76	-44.40	-43.20	-41.70	-40.98	-41.28	-40.56	-39.30	-38.46
-38.52	-35.88	-31.80	-29.64	-30.42	-30.54	-29.88	-29.16	-28.62	-28.50
-28.86	-28.32	-27.12	-25.86	-25.08	-25.74	-27.42	-30.06	-32.40	-34.20
-34.56	-35.58	-36.78	-36.48	-34.92	-33.90	-33.96	-33.66	-33.30	-30.84
-27.42	-25.62	-26.28	-26.28	-25.62	-25.44	-25.86	-25.38	-24.36	-22.92
-21.78	-21.54	-22.26	-22.14	-21.06	-20.28	-20.22	-20.10	-20.10	-19.86
-19.44	-18.48	-17.46	-15.96	-14.70	-14.16	-14.64	-14.82	-14.58	-14.58
-14.82	-15.72	-16.74	-19.14	-21.78	-25.74	-29.04	-35.70	-42.48	-65.34
-93.30	-111.66	-111.66							
-46.32	-45.78	-44.82	-43.14	-41.76	-42.24	-43.92	-44.52	-43.56	-43.44
-44.40	-41.22	-35.58	-32.82	-34.14	-34.44	-33.60	-33.18	-33.30	-32.88
-31.98	-29.16	-26.16	-24.84	-25.86	-27.72	-29.46	-31.80	-33.78	-35.70
-36.48	-37.62	-38.46	-37.62	-35.76	-34.80	-35.34	-35.58	-35.58	-33.24
-29.52	-26.82	-26.46	-26.04	-25.92	-25.80	-25.68	-25.08	-24.36	-23.16
-22.02	-21.54	-22.02	-21.48	-20.34	-19.44	-19.44	-19.26	-19.08	-18.78
-18.36	-17.76	-17.16	-16.68	-16.38	-15.96	-15.60	-15.42	-15.60	-15.90
-16.02	-17.46	-19.38	-22.98	-26.40	-32.22	-36.90	-47.28	-56.94	-83.70
-113.88	-133.80	-133.80							
-46.68	-46.14	-44.46	-42.84	-42.00	-42.60	-44.88	-45.48	-44.34	-44.16
-44.64	-41.46	-36.06	-33.36	-34.92	-35.16	-33.84	-33.42	-34.14	-33.72
-32.52	-29.64	-26.16	-24.90	-26.58	-28.50	-29.70	-31.98	-33.90	-35.88
-37.32	-38.40	-38.70	-37.80	-35.88	-34.92	-35.40	-35.64	-35.40	-33.06
-30.24	-27.48	-26.16	-25.68	-26.16	-26.10	-25.62	-25.02	-24.54	-23.34
-22.14	-21.60	-21.84	-21.30	-20.22	-19.32	-19.08	-18.90	-18.78	-18.48
-18.12	-17.52	-17.16	-16.74	-16.86	-16.44	-15.72	-15.54	-15.90	-16.14
-16.26	-17.70	-19.98	-23.58	-26.82	-32.70	-39.12	-49.74	-60.90	-87.72
-116.82	-136.74	-136.74							
-46.14	-46.32	-45.84	-45.06	-44.52	-45.48	-47.28	-47.82	-46.68	-45.36
-44.58	-42.12	-39.54	-38.16	-38.82	-38.94	-38.40	-38.04	-38.10	-37.14
-35.58	-32.22	-28.86	-27.24	-28.32	-30.30	-32.16	-34.14	-35.22	-37.26
-39.00	-40.02	-39.78	-38.22	-36.18	-35.22	-35.88	-36.42	-36.60	-34.74

-31.92	-28.80	-27.06	-26.34	-27.12	-26.94	-25.92	-24.78	-24.12	-23.22
-22.68	-21.78	-21.12	-20.22	-19.62	-18.84	-18.36	-18.00	-18.00	-17.94
-17.82	-17.64	-17.52	-17.58	-17.82	-17.46	-16.74	-16.68	-17.28	-18.90
-20.64	-23.70	-26.46	-30.06	-32.40	-41.34	-52.20	-71.46	-89.10	-117.18
-140.28	-156.42	-156.42							
-45.42	-46.32	-47.58	-48.30	-47.88	-47.70	-48.06	-47.64	-46.92	-45.60
-44.22	-42.90	-42.36	-41.70	-41.46	-41.58	-42.00	-41.64	-40.74	-39.00
-37.38	-34.86	-32.46	-31.62	-32.22	-33.84	-35.76	-36.84	-37.02	-37.98
-39.30	-39.36	-38.46	-37.32	-36.36	-36.30	-36.84	-37.68	-38.52	-36.78
-33.36	-29.94	-28.56	-27.54	-27.66	-26.82	-25.56	-24.18	-23.34	-22.80
-22.80	-21.96	-20.64	-19.68	-19.56	-19.08	-18.60	-18.36	-18.42	-18.42
-18.36	-18.60	-18.90	-19.08	-18.90	-18.48	-18.06	-18.24	-18.90	-22.68
-27.06	-32.34	-35.16	-37.68	-38.76	-52.38	-69.54	-95.76	-115.80	-141.60
-160.32	-172.98	-172.98							
-45.36	-46.20	-47.76	-48.54	-48.48	-48.30	-47.94	-47.46	-46.98	-45.72
-44.52	-43.20	-42.54	-41.94	-41.70	-41.76	-42.12	-41.76	-40.92	-39.18
-37.50	-34.98	-33.36	-32.58	-33.78	-35.40	-36.36	-37.38	-37.26	-38.16
-39.36	-39.30	-37.68	-36.54	-36.78	-36.84	-37.08	-37.92	-38.82	-37.14
-33.78	-30.36	-28.74	-27.72	-27.48	-26.64	-25.38	-24.00	-23.34	-22.80
-22.80	-21.96	-20.64	-19.74	-19.62	-19.20	-18.72	-18.42	-18.60	-18.60
-18.42	-18.72	-19.38	-19.56	-19.26	-18.78	-18.48	-18.66	-19.20	-23.10
-28.62	-33.96	-36.66	-39.00	-39.42	-53.28	-74.58	-100.86	-118.62	-144.24
-162.36	-175.02	-175.02							
-47.94	-48.36	-49.20	-49.92	-50.22	-49.32	-47.88	-46.74	-46.62	-46.08
-45.42	-44.28	-43.32	-42.24	-41.76	-41.52	-41.64	-41.76	-41.64	-41.10
-40.26	-39.00	-38.04	-37.86	-38.70	-39.54	-39.96	-39.84	-39.36	-39.30
-39.84	-39.30	-37.98	-37.08	-37.20	-37.38	-37.62	-38.34	-39.12	-38.28
-36.30	-32.94	-30.24	-28.02	-27.72	-26.34	-24.66	-23.10	-22.56	-22.38
-22.62	-22.08	-21.06	-20.46	-20.58	-20.22	-19.62	-19.26	-19.38	-19.32
-19.08	-19.92	-21.36	-22.50	-22.56	-23.16	-23.82	-24.84	-25.56	-29.76
-34.92	-40.44	-42.96	-45.48	-46.20	-62.70	-84.90	-113.52	-130.98	-157.86
-177.24	-191.40	-191.40							
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-46.32	-45.30	-44.22	-43.14	-42.48	-42.30	-42.42	-42.84	-43.44	-43.56
-43.56	-42.90	-42.00	-41.46	-41.34	-41.82	-42.60	-42.72	-42.12	-41.82
-41.88	-41.34	-40.74	-39.42	-38.34	-37.68	-37.86	-38.16	-38.64	-38.88
-38.58	-35.46	-31.38	-28.08	-27.84	-26.22	-24.12	-22.50	-22.08	-21.90
-22.26	-22.26	-21.78	-21.66	-21.78	-21.48	-20.82	-20.52	-20.58	-21.66
-22.26	-23.94	-25.44	-26.52	-27.06	-29.22	-31.44	-35.58	-37.68	-40.50
-42.66	-45.06	-47.70	-54.66	-59.28	-78.42	-98.28	-124.98	-144.06	-171.72
-193.44	-208.44	-208.44							
-52.20	-52.56	-51.66	-50.94	-50.76	-49.50	-48.00	-46.92	-47.04	-46.86
-46.50	-45.54	-44.58	-43.50	-43.02	-42.90	-43.14	-43.56	-43.92	-43.98
-43.68	-42.96	-42.30	-41.76	-41.76	-42.30	-43.02	-43.20	-42.78	-42.48
-42.66	-42.00	-40.98	-39.60	-38.82	-38.10	-37.92	-38.16	-38.64	-38.94
-38.82	-35.70	-31.56	-28.14	-27.60	-25.92	-24.12	-22.56	-22.20	-22.02
-22.08	-22.08	-22.02	-21.96	-21.90	-21.54	-21.12	-20.82	-20.94	-22.14
-23.76	-25.56	-26.46	-27.42	-27.72	-30.00	-32.76	-37.14	-40.68	-43.44
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-195.12	-210.30	-210.30							
-56.22	-56.10	-54.48	-52.32	-51.36	-50.10	-49.32	-48.90	-48.84	-48.36
-47.88	-47.40	-46.98	-46.68	-46.44	-46.38	-46.68	-46.44	-46.14	-45.48
-44.88	-44.40	-44.10	-44.16	-44.40	-45.06	-45.72	-46.14	-46.02	-46.20
-46.44	-45.12	-43.20	-40.98	-40.14	-38.82	-38.10	-37.86	-38.28	-38.94

-39.42	-36.72	-32.34	-28.92	-28.20	-26.52	-24.78	-23.34	-23.10	-22.80
-22.62	-22.56	-22.80	-22.68	-22.50	-22.74	-22.92	-23.88	-24.54	-26.76
-29.40	-31.68	-32.28	-33.48	-33.78	-36.00	-39.06	-43.26	-47.58	-50.52
-49.86	-52.08	-54.48	-67.80	-82.68	-108.90	-129.06	-153.42	-167.58	-189.78
-208.20	-220.68	-220.68							
-57.18	-57.00	-55.20	-52.98	-51.42	-50.16	-49.98	-49.56	-49.20	-48.66
-48.18	-47.76	-47.76	-47.52	-47.28	-47.16	-47.22	-46.92	-46.32	-45.60
-45.18	-44.70	-44.70	-44.82	-45.06	-45.66	-46.26	-46.68	-46.74	-46.92
-47.16	-45.84	-43.68	-41.34	-40.08	-38.70	-37.98	-37.74	-38.04	-38.76
-39.48	-36.78	-32.64	-29.10	-28.74	-27.06	-25.14	-23.64	-23.40	-23.10
-23.04	-22.92	-22.80	-22.74	-22.62	-22.92	-23.58	-24.72	-25.86	-28.08
-29.82	-32.16	-33.54	-34.86	-35.58	-37.80	-39.90	-43.98	-46.50	-49.56
-51.48	-53.94	-56.22	-69.96	-86.82	-113.76	-133.92	-158.70	-171.66	-193.98
-210.24	-222.72	-222.72							
-62.10	-61.08	-59.46	-56.76	-54.54	-52.86	-53.04	-52.50	-51.78	-51.00
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-47.22	-47.34	-47.40	-47.40	-47.52	-48.00	-48.54	-49.14	-49.38	-49.68
-49.86	-47.88	-45.24	-42.18	-40.74	-39.30	-38.64	-38.46	-38.76	-39.24
-39.78	-37.44	-33.72	-30.78	-30.42	-29.16	-27.66	-26.70	-26.52	-26.70
-26.94	-27.06	-26.82	-26.10	-25.56	-27.00	-29.16	-32.04	-33.48	-35.16
-36.24	-38.22	-40.02	-41.76	-42.66	-43.80	-44.70	-46.38	-47.64	-52.08
-56.58	-63.30	-67.02	-83.28	-101.40	-130.86	-152.70	-177.42	-188.76	-207.60
- 222.12	-232.86	-232.86							
-62.82	-61.74	-60.60	-57.96	-55.62	-53.88	-53.70	-53.16	-52.44	-51.66
-51.30	-50.82	-50.34	-49.86	-49.50	-49.38	-49.80	-49.26	-48.30	-47.70
-47.94	-48.06	-47.94	-47.94	-47.88	-48.30	-48.96	-49.56	-49.80	-50.10
-50.16	-48.18	-45.30	-42.24	-41.04	-39.60	-39.06	-38.88	-39.30	-39.72
-39.72	-37.38	-34.26	-31.26	-30.48	-29.22	-28.50	-27.66	-27.60	-27.78
-28.26	-28.44	-28.50	-27.72	-26.58	-28.08	-31.38	-34.38	-35.40	-37.08
-38.22	-40.20	-41.52	-43.20	-43.80	-44.82	-45.36	-47.10	-48.96	-53.46
-57.90	-64.80	-70.38	-86.70	-103.20	-132.78	-155.70	-180.54	-190.92	-209.76
-224.22	-235.02	-235.02							
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-54.00	-52.98	-51.96	-50.70	-50.16	-50.16	-50.82	-50.70	-49.92	-49.56
-49.86	-50.04	-49.98	-49.68	-49.38	-49.38	-49.86	-50.34	-50.58	-50.82
-50.94	-49.68	-47.52	-45.12	-43.86	-42.42	-41.94	-41.40	-41.46	-40.56
-39.84	-37.86	-35.94	-34.80	-34.44	-34.20	-33.96	-33.66	-33.54	-33.06
-32.94	-33.84	-35.04	-35.46	-34.08	-35.82	-39.54	-42.66	-43.32	-44.28
-45.06	-46.32	-47.40	-48.54	-48.90	-49.56	-49.86	-52.62	-55.62	-62.76
-68.22	-79.50	-87.72	-105.84	-120.90	-148.80	-171.06	-196.38	-207.42	-224.70
-236.70	-244.98	-244.98							
-65.64	-64.38	-63.66	-61.68	-59.94	-57.72	-56.40	-55.32	-55.08	-54.66
-54.42	-53.40	-52.26	-51.00	-50.34	-50.34	-50.88	-50.82	-50.22	-49.86
-49.98	-50.16	-50.28	-49.98	-49.56	-49.56	-49.80	-50.22	-50.46	-50.76
-50.88	-49.80	-48.66	-46.38	-44.76	-43.26	-42.78	-42.24	-41.70	-40.74
-39.66	-37.74	-36.60	-35.64	-36.24	-36.12	-35.58	-35.22	-35.04	-34.44
-33.36	-34.26	-36.66	-37.20	-36.18	-37.86	-41.04	-44.04	-44.64	-45.48
-45.84	-47.10	-48.24	-49.38	-49.98	-50.64	-51.00	-53.88	-57.60	-64.92
-71.88	-83.40	-92.82	-111.06	-126.24	-153.90	-174.48	-199.80	-212.64	-229.74
-239.10	-247.08	-247.08							
-67.80	-66.24	-65.70	-64.38	-63.12	-61.02	-59.46	-57.90	-57.60	-57.00
-56.70	-56.10	-55.44	-54.06	-52.92	-52.08	-52.38	-52.14	-51.60	-50.94
-50.82	-51.00	-51.36	-51.54	-51.24	-50.76	-50.58	-50.10	-50.10	-50.28
-50.64	-50.88	-50.76	-49.44	-47.76	-46.50	-46.20	-45.12	-43.98	-42.30

-41.28	-39.54	-38.52	-38.64	-40.14	-41.46	-41.34	-41.22	-40.86	-40.62
-39.96	-40.98	-42.96	-43.86	-43.50	-44.82	-46.86	-48.54	-48.96	-49.14
-49.08	-50.40	-52.02	-54.18	-55.02	-56.64	-57.54	-62.34	-67.08	-78.12
-86.88	-101.88	-112.14	-133.02	-149.22	-175.14	-192.54	-216.30	-230.46	-246.84
-253.92	-259.38	-259.38							
-68.34	-66.84	-66.42	-65.16	-64.08	-61.98	-60.54	-58.92	-58.32	-57.66
-57.24	-56.70	-56.70	-55.32	-53.64	-52.68	-52.86	-52.56	-51.90	-51.24
-50.94	-51.12	-51.66	-51.90	-51.72	-51.30	-50.82	-50.28	-49.92	-50.04
-50.64	-50.94	-50.82	-49.56	-48.18	-46.92	-46.98	-45.84	-44.40	-42.78
-42.18	-40.44	-38.70	-38.76	-40.32	-41.70	-42.30	-42.24	-41.88	-41.76
-42.60	-43.62	-43.98	-44.76	-44.88	-46.14	-47.58	-49.20	-49.50	-49.68
-49.50	-50.88	-53.04	-55.26	-56.28	-57.96	-59.40	-64.32	-69.66	-80.88
-90.66	-105.72	-115.80	-136.80	-154.44	-180.36	-195.90	-219.54	-233.64	-250.08
-257.10	-262.62	-262.62							
-70.38	-69.12	-69.00	-68.28	-67.32	-65.76	-64.56	-63.06	-62.22	-61.38
-61.02	-60.36	-60.12	-58.68	-57.12	-55.74	-55.38	-54.60	-54.00	-52.74
-51.90	-51.54	-52.26	-52.80	-52.80	-52.32	-51.72	-50.64	-49.86	-49.74
-50.46	-51.00	-51.00	-50.46	-49.50	-48.96	-49.08	-47.46	-45.54	-43.92
-43.80	-42.60	-40.68	-40.68	-42.24	-44.52	-45.84	-46.32	-45.60	-46.74
-48.90	-50.16	-49.44	-49.44	-49.98	-50.88	-51.60	-51.90	-51.90	-52.56
-53.16	-55.98	-58.62	-62.52	-64.56	-67.98	-69.84	-77.58	-84.84	-99.72
-110.70	-127.62	-138.12	-162.66	-183.00	-206.70	-218.16	-234.78	-247.62	-262.26
-269.34	-274.80	-274.80							
-70.74	-69.48	-69.54	-68.82	-67.86	-66.30	-65.40	-63.96	-63.18	-62.34
-62.22	-61.44	-60.36	-58.86	-58.02	-56.64	-55.86	-55.02	-54.66	-53.34
-51.96	-51.54	-52.26	-52.80	-52.80	-52.32	-51.78	-50.70	-49.86	-49.74
-50.46	-51.00	-51.00	-50.46	-49.92	-49.38	-49.32	-47.64	-45.36	-43.74
-43.80	-42.66	-41.40	-41.40	-42.90	-45.18	-46.68	-47.10	-46.20	-47.28
-49.56	-50.82	-50.40	-50.40	-51.00	-51.90	-52.38	-52.62	-52.26	-52.98
-54.66	-57.66	-60.18	-64.26	-67.32	-70.86	-72.72	-80.70	-89.64	-104.88
-116.16	-133.32	-144.42	-169.44	-191.22	-214.98	-222.72	-238.98	-249.90	-264.48
-271.44	-276.96	-276.96							
-72.42	-71.46	-71.46	-70.80	-70.02	-69.06	-68.34	-67.68	-67.26	-66.48
-65.94	-64.26	-62.70	-61.32	-60.90	-59.94	-58.92	-58.02	-57.72	-56.34
-54.72	-53.46	-53.64	-53.40	-53.34	-52.80	-52.26	-51.18	-50.28	-49.86
-50.34	-50.64	-50.70	-50.52	-50.22	-49.86	-49.68	-47.94	-45.54	-44.28
-44.64	-44.94	-44.64	-45.24	-46.38	-48.12	-49.62	-50.76	-50.28	-51.66
-53.64	-54.60	-54.18	-54.66	-55.56	-56.88	-57.36	-57.84	-57.54	-59.34
-61.80	-66.00	-68.88	-76.02	-81.48	-88.80	-91.50	-102.54	-113.58	-131.16
-143.10	-160.32	-171.60	-196.14	-218.70	-239.52	-244.98	-255.84	-264.72	-274.80
-280.62	-284.34	-284.34							
-73.08	-72.06	-71.70	-71.04	-70.56	-69.54	-68.88	-68.22	-68.28	-67.44
-66.24	-64.50	-63.36	-62.04	-61.50	-60.48	-59.76	-58.86	-58.50	-57.12
-55.86	-54.54	-54.06	-53.76	-53.58	-53.04	-52.38	-51.30	-50.52	-50.04
-50.16	-50.40	-50.58	-50.40	-49.98	-49.62	-49.56	-47.82	-45.84	-44.58
-45.12	-45.54	-45.72	-46.38	-47.04	-48.72	-50.10	-51.30	-51.78	-53.22
-54.60	-55.50	-54.96	-55.44	-56.58	-57.96	-58.80	-59.40	-59.64	-61.50
-63.72	-67.98	-71.10	-78.66	-85.80	-93.54	-97.20	-108.60	-119.76	-137.70
-149.34	-166.80	-176.88	-201.60	-221.76	-242.88	-249.06	-260.10	-267.84	-277.86
-281.82	-285.42	-285.42							
-74.88	-74.04	-73.38	-72.72	-72.48	-71.88	-71.22	-71.10	-71.58	-70.50
-68.58	-66.72	-66.06	-65.28	-64.80	-64.44	-64.26	-63.60	-62.94	-61.86
-61.08	-59.52	-58.20	-56.40	-55.68	-54.06	-53.10	-51.72	-51.06	-50.34
-50.04	-49.92	-50.10	-49.74	-49.20	-49.08	-49.32	-48.72	-47.34	-47.04

-47.82	-49.02	-49.80	-50.82	-51.18	-52.32	-53.46	-55.26	-56.64	-58.26
-59.16	-60.18	-60.18	-61.92	-63.54	-65.94	-67.26	-68.88	-69.60	-71.64
-73.74	-78.78	-82.92	-93.96	-103.68	-115.68	-121.14	-136.26	-149.52	-169.20
-181.20	-196.56	-205.56	-223.80	-241.08	-258.36	-265.56	-276.36	-283.56	-290.76
-293.16	-294.96	-294.96							
-75.18	-74.34	-73.80	-73.14	-72.96	-72.30	-71.76	-71.64	-72.12	-71.04
-69.18	-67.20	-66.66	-65.94	-65.70	-65.46	-65.58	-64.92	-64.02	-62.94
-62.46	-60.84	-59.40	-57.48	-56.22	-54.42	-53.16	-51.72	-51.18	-50.46
-50.10	-49.86	-49.98	-49.62	-48.96	-48.90	-49.50	-48.96	-47.94	-47.70
-48.54	-49.80	-50.64	-51.66	-52.20	-53.40	-54.42	-56.22	-57.48	-59.16
-59.94	-61.08	-61.98	-63.84	-65.70	-68.22	-69.66	-71.28	-72.00	-74.10
-76.08	-81.24	-86.04	-97.50	-107.64	-120.12	-126.24	-141.96	-156.48	-176.82
-188.40	-204.00	-211.80	-230.10	-244.20	-261.66	-268.56	-279.66	-286.56	-293.94
-296.28	-298.14	-298.14							
-77.28	-76.68	-76.08	-75.18	-74.82	-74.40	-74.10	-74.34	-74.82	-73.80
-71.94	-70.32	-69.90	-69.18	-68.88	-68.70	-69.06	-68.76	-67.86	-67.02
-66.66	-65.40	-63.96	-61.74	-59.94	-57.18	-55.32	-53.52	-53.10	-51.96
-51.12	-50.40	-50.52	-50.16	-49.44	-49.62	-50.58	-50.88	-50.22	-50.22
-51.00	-52.74	-54.18	-56.22	-57.18	-58.98	-60.18	-62.22	-63.48	-64.92
-65.58	-67.50	-69.42	-71.94	-73.80	-77.22	-79.74	-83.40	-84.78	-88.32
-90.78	-96.90	-102.36	-115.74	-127.92	-143.64	-151.50	-167.76	-182.82	-202.68
-215.34	-230.52	-237.78	-250.44	-261.24	-274.80	-282.66	-293.40	-300.00	-307.20
-310.20	-312.84	-312.84							
-78.00	-77.34	-76.62	-75.66	-75.18	-74.70	-74.70	-74.94	-75.42	-74.40
-72.72	-71.04	-70.74	-69.96	-69.30	-69.00	-69.18	-68.88	-68.46	-67.62
-67.08	-65.82	-64.80	-62.58	-61.02	-58.14	-56.10	-54.24	-53.94	-52.74
-51.42	-50.64	-50.94	-50.58	-49.86	-50.04	-51.00	-51.30	-50.70	-50.70
-51.24	-53.04	-54.96	-57.24	-58.38	-60.30	-61.80	-63.96	-65.22	-66.72
-67.26	-69.18	-71.04	-73.62	-74.82	-78.48	-81.90	-85.98	-88.08	-91.92
-95.04	-101.34	-106.14	-120.00	-132.72	-149.10	-157.44	-174.00	-185.88	-206.16
-219.12	-234.84	-241.74	-254.64	-263.34	-277.14	-285.48	-296.58	-302.04	-309.42
-313.20	-315.96	-315.96							
-80.22	-79.50	-78.60	-77.46	-76.68	-76.38	-76.74	-77.46	-77.94	-77.40
-75.90	-74.76	-74.46	-73.38	-72.24	-71.34	-71.28	-70.92	-70.74	-69.96
-69.24	-68.40	-67.86	-66.84	-65.64	-63.48	-61.38	-59.40	-58.86	-56.82
-54.90	-53.76	-54.18	-54.00	-53.34	-52.86	-53.28	-53.40	-53.28	-53.76
-54.12	-56.16	-58.68	-61.38	-62.76	-66.24	-69.00	-72.48	-73.86	-75.36
-75.96	-77.94	-79.86	-82.62	-83.88	-89.04	-94.14	-100.92	-104.52	-110.40
-114.42	-123.36	-129.84	-144.00	-156.78	-172.98	-183.30	-198.42	-208.14	-225.18
-239.10	-254.40	-261.66	-272.40	-279.66	-291.36	-300.42	-310.32	-315.18	-321.54
-325.74	-328.50	-328.50							
-80.34	-79.56	-78.96	-77.76	-76.92	-76.62	-77.16	-77.88	-78.36	-77.82
-76.74	-75.54	-75.18	-74.04	-73.08	-72.12	-72.00	-71.64	-71.22	-70.38
-69.66	-68.82	-68.58	-67.56	-66.72	-64.62	-63.06	-61.02	-60.06	-57.96
-56.10	-54.90	-55.20	-55.02	-54.48	-53.88	-53.58	-53.64	-54.00	-54.60
-55.08	-57.24	-59.34	-62.10	-63.36	-67.08	-70.74	-74.46	-75.72	-77.28
-78.00	-80.04	-81.90	-84.78	-86.70	-92.22	-97.38	-104.52	-108.48	-114.60
-118.38	-127.86	-136.56	-151.26	-160.86	-177.48	-188.10	-203.82	-213.00	-230.58
-243.00	-258.66	-265.56	-276.66	-283.56	-295.56	-303.42	-313.56	-318.18	-324.60
-327.84	-330.54	-330.54							
-81.30	-80.46	-79.98	-79.20	-78.36	-78.18	-78.78	-79.26	-79.62	-79.68
-79.26	-78.84	-78.42	-77.40	-76.44	-75.30	-74.88	-73.92	-73.20	-72.30
-71.70	-71.22	-71.16	-70.68	-70.08	-69.00	-67.98	-66.42	-65.10	-62.94
-61.08	-59.94	-60.12	-59.94	-59.52	-58.02	-56.58	-55.98	-56.88	-58.86

-60.18	-62.46	-64.08	-67.56	-69.96	-74.88	-79.08	-82.74	-84.18	-86.22
-87.24	-89.88	-92.10	-94.26	-95.88	-102.60	-109.86	-120.60	-126.06	-133.62
-137.76	-149.04	-160.62	-175.68	-184.14	-196.80	-206.64	-221.88	-233.34	-251.04
-262.62	-276.90	-284.76	-296.28	-303.60	-312.66	-318.78	-325.20	-329.46	-335.70
-339.24	-342.72	-342.72							
-81.54	-80.70	-80.22	-79.38	-78.90	-78.72	-78.96	-79.44	-79.62	-79.74
-79.68	-79.32	-79.02	-78.00	-77.10	-75.90	-75.24	-74.22	-73.56	-72.60
-72.18	-71.76	-71.58	-71.04	-70.44	-69.36	-68.58	-67.02	-65.94	-63.72
-62.16	-60.96	-61.02	-60.84	-60.54	-58.92	-57.24	-56.58	-57.36	-59.52
-61.56	-63.96	-65.04	-68.76	-72.60	-77.82	-80.46	-84.12	-85.80	-87.96
-89.04	-91.80	-94.32	-96.42	-96.18	-103.14	-112.02	-123.48	-129.42	-137.46
-141.66	-153.30	-163.44	-179.22	-188.82	-201.72	-207.78	-223.50	-236.76	-255.30
-265.44	-280.26	-288.48	-300.54	-307.44	-316.68	-320.82	-327.24	-330.48	-337.02
-342.00	-345.72	-345.72							
-82.20	-81.30	-80.88	-80.52	-80.34	-80.22	-80.22	-80.34	-80.40	-80.88
-81.42	-81.90	-81.72	-81.00	-80.04	-78.72	-77.76	-76.62	-75.90	-75.00
-74.64	-74.10	-73.86	-73.02	-72.18	-71.22	-70.74	-69.96	-69.06	-67.56
-66.12	-64.92	-64.74	-64.20	-63.90	-62.82	-61.14	-60.54	-61.08	-64.20
-67.74	-71.64	-72.60	-77.58	-83.28	-88.32	-89.70	-92.58	-94.92	-97.74
-99.06	-103.02	-106.56	-109.14	-107.76	-115.44	-126.84	-140.22	-147.54	-156.42
-161.28	-173.64	-184.50	-200.58	-211.62	-222.30	-225.84	-240.12	-256.02	-273.18
-282.36	-295.80	-305.52	-317.16	-323.88	-330.24	-332.64	-336.24	-338.64	-344.94
-351.72	-356.22	-356.22							
-82.26	-81.30	-81.00	-80.64	-80.52	-80.46	-80.46	-80.52	-80.70	-81.24
-81.84	-82.32	-82.32	-81.60	-80.70	-79.26	-78.48	-77.28	-76.62	-75.66
-75.18	-74.64	-74.40	-73.44	-72.54	-71.52	-71.16	-70.32	-69.66	-68.10
-66.90	-65.58	-65.16	-64.62	-64.26	-63.12	-62.28	-61.74	-62.04	-65.28
-69.06	-73.26	-74.88	-80.10	-84.90	-90.06	-91.62	-94.68	-97.02	-100.02
-101.40	-105.60	-109.50	-112.44	-112.56	-120.60	-130.68	-144.42	-151.32	-160.56
-165.18	-178.20	-190.02	-206.70	-215.52	-226.62	-231.60	-246.42	-259.80	-277.32
-285.18	-299.10	-308.28	-320.28	-325.80	-332.28	-334.56	-338.28	-340.56	-347.04
-352.62	-357.24	-357.24							
-82.08	-81.36	-81.24	-81.24	-81.24	-81.30	-81.36	-81.60	-81.84	-82.74
-83.58	-84.30	-84.42	-83.88	-83.04	-82.02	-81.36	-80.28	-79.50	-78.36
-77.64	-76.92	-76.68	-75.84	-74.76	-73.80	-73.44	-72.66	-72.12	-70.62
-69.30	-67.98	-67.38	-66.90	-66.54	-65.94	-65.64	-66.72	-67.74	-73.50
-78.72	-84.66	-87.12	-90.42	-93.72	-98.28	-101.22	-106.02	-108.66	-112.02
-113.88	-118.92	-123.78	-129.78	-132.42	-141.12	-150.30	-161.94	-169.26	-179.82
-185.82	-200.04	-213.54	-227.16	-233.88	-245.40	-253.80	-268.92	-280.50	-294.78
-302.64	-314.28	-322.92	-331.98	-336.84	-342.18	-344.64	-347.34	-349.26	-354.60
-360.00	-364.38	-364.38							
-82.02	-81.30	-81.30	-81.30	-81.30	-81.42	-81.54	-81.84	-82.08	-82.98
-83.94	-84.66	-84.66	-84.06	-83.46	-82.44	-81.84	-80.76	-79.92	-78.72
-78.06	-77.28	-77.04	-76.26	-75.48	-74.46	-73.98	-73.14	-72.54	-70.98
-69.54	-68.16	-67.86	-67.44	-67.20	-66.54	-65.94	-67.14	-69.48	-75.78
-81.54	-87.78	-89.76	-93.00	-94.62	-99.36	-103.56	-108.66	-111.06	-114.60
-116.58	-121.86	-126.42	-132.78	-136.20	-145.26	-153.12	-165.18	-172.02	-183.18
-190.38	-205.20	-216.36	-230.22	-235.80	-247.86	-257.34	-273.12	-283.26	-298.08
-306.30	-318.30	-324.90	-334.08	-338.70	-344.22	-346.56	-349.32	-350.28	-355.86
-361.74	-366.42	-366.42							
-81.90	-81.78	-81.96	-82.02	-82.02	-82.14	-82.32	-82.98	-83.52	-84.78
-85.80	-86.28	-86.04	-85.44	-84.90	-84.06	-83.58	-82.68	-81.84	-80.64
-79.86	-79.14	-78.96	-78.36	-77.76	-77.04	-76.50	-75.60	-74.76	-73.08
-71.52	-70.44	-70.38	-71.22	-71.82	-72.66	-72.00	-75.84	-80.76	-88.32

-94.50	-99.72	-101.76	-103.32	-103.08	-107.58	-113.82	-120.96	-123.96	-128.34
-130.80	-136.98	-142.38	-150.36	-155.22	-163.32	-170.04	-179.94	-187.26	-199.68
-209.46	-223.68	-233.46	-244.98	-250.38	-262.02	-273.12	-287.52	-297.24	-310.68
-319.92	-330.60	-336.00	-343.92	-348.84	-353.34	-355.26	-357.84	-358.92	-365.10
-371.88	-376.38	-376.38							
-82.14	-82.02	-82.14	-82.26	-82.26	-82.32	-82.44	-83.16	-84.06	-85.38
-86.10	-86.58	-86.34	-85.68	-85.08	-84.24	-83.82	-82.86	-82.20	-81.00
-80.22	-79.44	-79.38	-78.72	-78.00	-77.28	-77.10	-76.14	-75.24	-73.44
-72.24	-71.16	-70.98	-71.94	-73.38	-74.40	-74.58	-78.78	-84.06	-91.86
-96.00	-101.34	-103.62	-105.24	-105.18	-109.80	-115.62	-123.18	-126.72	-131.40
-133.68	-140.16	-146.10	-154.44	-159.00	-167.34	-172.92	-183.12	-189.96	-202.98
-212.16	-226.98	-236.16	-248.16	-254.10	-266.10	-274.98	-289.74	-298.98	-312.84
-320.70	-331.80	-337.74	-346.08	-350.64	-355.26	-356.28	-359.04	-361.68	-368.16
-373.74	-378.36	-378.36							
-82.92	-83.40	-83.70	-83.94	-83.82	-83.82	-83.94	-85.02	-86.40	-87.36
-87.72	-87.54	-87.24	-86.82	-86.28	-85.62	-85.08	-84.30	-83.82	-82.68
-81.66	-80.94	-81.00	-80.58	-79.80	-79.32	-79.44	-78.84	-77.76	-76.98
-76.38	-76.44	-76.38	-80.22	-84.06	-88.20	-89.16	-93.06	-98.70	-104.04
-106.44	-110.70	-113.76	-116.04	-116.04	-121.08	-127.56	-136.14	-141.00	-147.18
-150.18	-157.26	-164.04	-172.14	-177.00	-184.92	-190.38	-200.10	-207.42	-219.06
-228.24	-240.84	-250.08	-261.72	-269.04	-278.88	-285.66	-298.14	-308.46	-320.88
-327.66	-336.72	-343.50	-351.54	-356.46	-360.84	-361.38	-366.54	-372.00	-379.14
-383.46	-386.16	-386.16							
-83.04	-83.58	-84.24	-84.54	-84.24	-84.24	-84.54	-85.62	-86.76	-87.78
-87.84	-87.66	-87.30	-86.82	-86.64	-85.98	-85.44	-84.60	-84.12	-82.92
-81.84	-81.12	-81.24	-80.88	-80.34	-79.92	-79.86	-79.20	-78.48	-77.76
-77.70	-77.82	-78.12	-82.32	-87.54	-92.04	-92.52	-96.36	-100.38	-105.84
-108.42	-112.86	-115.86	-118.26	-118.26	-123.60	-130.20	-139.20	-143.82	-150.30
-153.90	-161 28	-166.92	-175.20	-179.82	-188.16	-194.04	-204.24	-211.14	-223.14
-231.06	-243.96	-251.88	-263.88	-270.78	-280.98	-286.56	-299.52	-310.02	-322.98
-328.56	-337.80	-343.38	-351.72	-356.28	-360.96	-362.22	-367.80	-373.68	-381.12
-384.42	-387.18	-387.18							
-84.72	-85.44	-86.52	-86.82	-86.28	-86.04	-86.40	-87.30	-88.32	-88.86
-88.62	-87.96	-87.42	-87.12	-87.30	-86.94	-86.28	-85.62	-85.20	-84.24
-83.04	-82.62	-82.98	-83.22	-82.98	-82.80	-82.62	-82.50	-82.26	-83.94
-85.50	-89.04	-90.60	-96.42	-103.14	-107.52	-107.76	-109.98	-112.56	-116.76
-119.88	-124.26	-127.44	-130.44	-130.98	-137.34	-145.02	-154.14	-159.00	-165.30
-169.62	-176.76	-182.16	-190.14	-195.00	-204.72	-212.58	-223.26	-230.04	-239.10
-245.88	-255.72	-263.04	-272.88	-279.66	-289.38	-295.38	-307.80	-318.96	-329.76
-334.62	-342.54	-348.00	-355.92	-360.84	-383.34	-397.32	-406.08	-402.96	-395.34
-398.34	-400.92	-400.92							
-85.32	-86.04	-86.94	-87.18	-86.64	-86.34	-86.52	-87.48	-88.38	-88.92
-88.68	-88.08	-87.48	-87.12	-87.18	-86.82	-86.28	-85.62	-85.44	-84.42
-83.40	-82.92	-83.40	-83.70	-83.58	-83.40	-83.28	-83.22	-83.28	-85.26
-87.84	-91.80	-94.38	-100.44	-105.18	-109.62	-110.16	-112.56	-115.08	-119.46
-122.34	-126.84	-129.54	-132.72	-133.98	-140.64	-147.78	-157.20	-161.76	-168.24
-171.54	-178.98	-184.86	-193.20	-197.76	-207.96	-216.18	-227.28	-232.86	-242.10
-247.74	-257.88	-264.78	-274.92	-280.56	-290.76	-297.90	-310.86	-319.80	-330.84
-335.46	-343.80	-349.68	-358.02	-362.64	-387.90	-417.18	-426.48	-408.96	-399.42
-403.02	-405.84	-405.84							
-87.72	-88.32	-88.98	-89.10	-88.44	-88.08	-88.08	-88.38	-89.10	-89.22
-88.98	-88.32	-87.66	-87.12	-87.06	-86.88	-86.58	-86.40	-86.34	-85.86
-85.08	-85.02	-85.56	-86.10	-86.28	-87.00	-87.36	-89.10	-90.18	-95.22
-99.96	-106.74	-110.94	-115.32	-117.72	-119.52	-120.30	-123.42	-126.84	-131.58

-134.40	-138.96	-141.96	-146.34	-148.80	-155.88	-163.20	-172.14	-177.00	-182.34
-184.80	-192.72	-200.58	-209.46	-213.84	-222.06	-230.70	-242.22	-248.76	-257.46
-261.84	-269.88	-277.20	-286.92	-292.38	-302.22	-310.92	-321.72	-329.04	-337.92
-342.84	-350.88	-357.66	-366.54	-372.00	-415.50	-469.26	-480.72	-442.20	-418.14
-423.00	-426.54	-426.54							
-88.08	-88.74	-89.28	-89.40	-88.92	-88.56	-88.56	-88.86	-89.10	-89.22
-88.98	-88.32	-87.78	-87.24	-87.12	-86.94	-86.82	-86.64	-86.52	-86.04
-85.68	-85.56	-85.86	-86.46	-86.82	-87.66	-88.44	-90.42	-92.28	-97.68
-102.72	-109.74	-113.52	-117.90	-119.52	-121.26	-121.68	-124.98	-128.76	-133.80
-136.32	-141.12	-144.72	-149.34	-151.62	-159.06	-165.96	-175.20	-179.76	-185.34
-187.62	-195.96	-204.18	-213.42	-216.72	-225.00	-231.66	-243.66	-252.12	-261.42
-264.72	-273.06	-279.96	-290.10	-296.04	-306.18	-312.78	-323.88	-330.78	-340.02
-344.64	-352.92	-358.56	-367.80	-373.68	-419.04	-469.62	-481.68	-446.16	-421.20
-425.76	-429.48	-429.48							
-89.88	-90.18	-90.66	-90.96	-90.78	-90.84	-90.96	-90.90	-90.66	-90.42
-90.18	-89.58	-88.98	-88.44	-88.32	-88.32	-88.44	-88.20	-87.90	-87.60
-87.54	-88.08	-88.56	-89.70	-90.48	-92.88	-94.92	-99.90	-103.62	-111.06
-117.06	-123.60	-126.96	-130.32	-131.46	-134.22	-135.30	-138.84	-142.62	-146.34
-148.80	-154.14	-159.00	-164.34	-166.80	-173.10	-179.88	-187.92	-192.84	-200.58
-204.72	-213.60	-221.70	-229.80	-233.34	-240.30	-245.22	-257.64	-269.88	-279.72
-281.58	-287.10	-293.88	-302.88	-309.66	-318.54	-324.00	-332.88	-339.66	-348.54
-354.00	-361.92	-366.84	-374.88	-381.66	-410.58	-454.38	-468.48	-442.86	-436.92
-442.38	-446.76	-446.76							
-90.12	-90.42	-90.84	-91.14	-91.02	-91.14	-91.38	-91.38	-91.14	-90.90
-90.78	-90.12	-89.40	-88.86	-88.92	-88.92	-88.86	-88.56	-88.20	-87.84
-87.72	-88.38	-89.40	-90.72	-91.44	-94.02	-96.66	-102.06	-106.38	-114.12
-119.64	-126.36	-129.18	-132.72	-134.28	-137.40	-139.98	-143.64	-145.68	-149.34
-151.68	-157.20	-161.82	-167.34	-169.68	-176.10	-181.74	-190.02	-194.64	-202.98
-209.16	-218.40	-223.74	-232.08	-236.94	-244.38	-249.00	-261.90	-273.42	-283.56
-284.58	-2[illegible]10	-295.74	-304.92	-310.56	-319.80	-325.68	-334.92	-340.56	-349.80
-355.68	-364.02	-368.64	-376.92	-382.56	-410.94	-438.36	-453.18	-444.48	-440.16
-446.04	-450.66	-450.66							
-91.62	-91.80	-92.40	-93.30	-93.60	-94.02	-94.26	-94.20	-94.02	-93.84
-93.78	-93.24	-92.46	-92.10	-92.28	-91.74	-91.26	-90.66	-90.36	-90.18
-89.94	-91.02	-92.82	-96.42	-98.40	-103.80	-107.88	-114.48	-119.76	-127.92
-133.92	-140.34	-142.80	-144.72	-146.04	-150.54	-156.00	-161.22	-161.76	-164.34
-166.80	-171.30	-175.68	-180.96	-184.02	-190.14	-195.06	-201.30	-205.68	-214.68
-223.92	-233.58	-237.18	-245.10	-251.88	-260.76	-266.22	-277.86	-288.96	-297.84
-298.98	-303.30	-307.68	-314.76	-320.22	-329.10	-335.88	-343.92	-348.84	-356.88
-363.66	-373.38	-379.38	-387.30	-391.68	-402.30	-412.68	-430.32	-443.10	-455.64
-461.34	-464.22	-464.22							
-91.92	-92.10	-92.82	-93.84	-94.50	-94.98	-94.92	-94.80	-94.74	-94.56
-94.38	-93.84	-93.30	-92.94	-93.06	-92.46	-91.62	-90.96	-91.02	-90.84
-90.60	-91.74	-93.30	-97.20	-100.74	-106.62	-110.70	-117.54	-121.92	-130.44
-136.62	-143.40	-145.68	-147.48	-147.18	-151.80	-157.74	-163.32	-164.58	-167.40
-169.68	-174.30	-177.60	-183.12	-186.78	-193.20	-197.82	-204.30	-207.60	-216.78
-224.76	-234.90	-239.82	-248.16	-253.74	-262.98	-268.92	-280.86	-289.80	-299.04
-301.68	-306.30	-309.60	-316.98	-322.92	-332.16	-337.74	-346.02	-350.64	-358.98
-364.56	-374.76	-381.96	-390.30	-393.60	-404.70	-415.20	-433.68	-446.52	-459.42
-462.48	-465.18	-465.18							
-93.54	-94.14	-95.22	-96.78	-97.80	-98.16	-97.74	-97.74	-97.92	-97.80
-97.44	-97.02	-96.84	-96.72	-96.72	-96.00	-94.74	-94.26	-94.74	-95.22
-95.28	-97.02	-98.88	-105.24	-111.66	-120.78	-126.06	-132.66	-136.26	-143.10
-149.88	-156.18	-158.64	-159.48	-157.56	-161.10	-167.88	-174.18	-176.64	-180.18

-182.64	-187.02	-190.02	-196.14	-201.06	-207.36	-211.68	-217.02	-220.02	-227.10
-233.88	-244.56	-252.48	-262.14	-267.06	-275.10	-281.88	-291.72	-299.10	-307.98
-312.84	-318.18	-320.64	-327.72	-335.10	-343.98	-348.84	-356.76	-362.22	-370.14
-375.06	-384.90	-394.14	-402.18	-404.64	-419.40	-434.46	-456.48	-469.98	-475.74
-473.46	-470.22	-470.22							
-93.96	-94.62	-95.82	-97.38	-98.10	-98.46	-98.16	-98.16	-98.58	-98.46
-97.98	-97.50	-97.38	-97.32	-97.32	-96.60	-95.70	-95.28	-95.58	-96.18
-96.60	-98.52	-100.74	-107.46	-113.88	-123.54	-129.36	-136.26	-139.20	-146.16
-151.80	-158.22	-160.56	-161.46	-160.50	-164.16	-169.80	-176.22	-178.56	-182.22
-184.56	-189.18	-192.78	-199.26	-203.88	-210.36	-213.66	-219.18	-222.78	-230.16
-235.80	-246.84	-255.12	-265.26	-269.88	-278.16	-283.80	-293.94	-300.84	-310.08
-314.70	-320.22	-322.56	-329.94	-336.84	-346.08	-350.70	-359.04	-364.98	-373.26
-377.88	-388.02	-395.[illegible]4	-404.22	-406.56	-422.28	-440.46	-463.56	-474.78	-480.24
-474.96	-471.18	-471.18							
-96.96	-97.74	-99.00	-100.08	-100.56	-100.56	-100.20	-100.26	-100.86	-100.98
-100.38	-100.44	-100.68	-100.86	-100.74	-100.26	-99.84	-99.60	-99.72	-100.92
-102.24	-107.10	-111.06	-119.16	-125.94	-136.56	-144.48	-152.40	-154.86	-159.36
-163.68	-169.02	-172.08	-175.50	-176.04	-179.58	-183.90	-188.40	-190.86	-194.40
-196.86	-202.20	-207.12	-213.36	-217.68	-223.02	-226.08	-231.36	-235.68	-243.66
-249.66	-260.34	-268.98	-278.82	-284.28	-292.20	-297.12	-305.16	-311.94	-319.98
-324.90	-330.24	-332.64	-339.78	-347.10	-356.82	-362.28	-370.32	-376.50	-384.60
-390.06	-399.78	-407.10	-415.86	-419.46	-443.10	-469.26	-491.70	-498.06	-494.76
-486.12	-480.66	-480.66							
-97.92	-98.76	-99.60	-100.68	-101.16	-101.16	-100.68	-100.68	-101.10	-101.16
-100.86	-100.98	-101.52	-101.70	-101.46	-100.98	-100.62	-100.38	-100.32	-101.64
-103.38	-108.54	-113.76	-122.22	-127.86	-138.90	-147.18	-155.46	-157.80	-162.36
-165.66	-171.18	-174.84	-178.56	-179.94	-183.60	-186.90	-191.46	-193.80	-197.46
-199.80	-205.32	-209.94	-216.36	-219.66	-225.18	-228.84	-234.36	-237.66	-246.00
-253.32	-264.36	-270.96	-281.04	-287.04	-295.32	-299.94	-308.22	-313.86	-322.14
-326.76	-332.28	-334.56	-341.94	-348.90	-359.04	-365.04	-373.32	-377.58	-385.86
-391.80	-401.94	-408.90	-418.14	-423.12	-448.08	-475.26	-498.24	-499.50	-495.72
-489.12	-483.66	-483.66							
-101.64	-102.36	-102.90	-103.44	-103.74	-103.74	-103.32	-103.38	-103.62	-103.80
-103.80	-104.16	-104.94	-105.24	-105.00	-104.88	-104.70	-105.36	-105.72	-109.92
-113.52	-121.44	-128.22	-136.26	-141.12	-150.18	-158.76	-166.86	-169.86	-175.08
-178.08	-183.42	-187.74	-192.24	-194.70	-199.08	-202.08	-205.68	-207.54	-211.08
-214.08	-219.42	-223.74	-228.24	-230.70	-236.82	-242.34	-248.46	-250.92	-258.96
-268.20	-278.82	-284.34	-294.06	-301.38	-309.42	-313.74	-320.04	-324.90	-332.04
-336.90	-342.24	-344.70	-351.78	-359.16	-369.00	-375.72	-382.86	-385.86	-394.62
-402.54	-414.06	-421.38	-435.30	-445.02	-468.48	-494.40	-507.42	-503.70	-499.86
-496.14	-494.22	-494.22							
-102.12	-102.90	-103.50	-104.04	-104.10	-104.10	-104.10	-104.16	-104.40	-104.58
-104.58	-104.94	-105.36	-105.72	-105.78	-105.72	-105.60	-106.38	-107.64	-112.20
-117.24	-125.52	-131.16	-139.38	-144.06	-153.18	-159.78	-168.00	-171.72	-177.24
-180.96	-186.48	-189.72	-194.34	-196.62	-201.24	-204.96	-208.62	-209.58	-213.24
-216.96	-222.48	-225.72	-230.34	-232.62	-239.10	-245.10	-251.58	-253.86	-262.14
-270.06	-281.10	-287.10	-297.24	-304.20	-312.48	-315.72	-322.14	-326.82	-334.14
-338.82	-344.34	-346.62	-354.00	-360.96	-371.04	-376.68	-384.00	-387.72	-396.96
-405.24	-417.24	-424.20	-439.02	-451.44	-475.20	-491.76	-504.48	-502.56	-498.96
-497.04	-495.24	-495.24							
-104.10	-104.94	-105.78	-106.26	-105.96	-106.02	-106.50	-106.98	-107.16	-107.28
-107.28	-107.64	-107.94	-109.20	-110.10	-111.60	-112.08	-116.10	-119.64	-126.72
-132.84	-140.88	-146.40	-155.16	-160.62	-166.92	-170.58	-176.88	-182.40	-189.48
-193.80	-198.30	-200.70	-204.30	-206.70	-211.26	-215.52	-219.06	-219.66	-224.04

```
-228.96 -234.30 -236.70 -239.46 -241.32 -247.56 -254.94 -263.70 -267.30 -275.28
-282.00 -291.84 -299.16 -309.84 -317.16 -324.30 -326.70 -332.88 -338.40 -345.48
-349.80 -355.14 -358.14 -366.12 -373.44 -381.48 -385.80 -392.88 -398.40 -408.24
-416.82 -427.56 -434.94 -451.86 -468.36 -482.88 -488.40 -492.06 -492.66 -496.80
-499.20 -502.50 -502.50
PLOTREC
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CHAPTER 6

CLHYD - A CURVILINEAR LONG WAVE HYDRODYNAMIC MODEL
THEORY AND PROGRAM DOCUMENTATION

PART I: INTRODUCTION

1. Use of time-dependent numerical models for simulating long-period wave behavior in open coastal waters, estuaries, bays, and lakes has increased rapidly in recent years. Two- and three-dimensional numerical solutions of the governing partial differential equations are employed in most shallow-water long-wave applications. This chapter documents the Curvilinear Long-wave HYDrodynamic (CLHYD) model. CLHYD is a two-dimensional, depth-averaged model for computing tidal circulation and storm surge propagation. This finite difference model is developed in boundary-fitted (curvilinear) coordinates.

2. CLHYD is a two-dimensional model; therefore, velocities are treated as depth-averaged quantities (i.e., velocities are constant in magnitude and direction over depth). The model solves finite difference approximations of the Navier-Stokes (continuity and horizontal momentum) equations for the water surface displacement (S) and the unit flow rate components (U and V). CLHYD can simulate flow fields induced by wind fields, river inflows/outflows, and tidal forcing.

3. The potential user must have a thorough understanding of the model's capabilities and limitations before applying it to a particular study. CLHYD is not a "total solution" to a hydrodynamic problem. The user must ensure that limitations imposed by shallow-water wave theory (i.e., water depth is sufficiently small when compared with wavelength) are applicable to the problem being investigated. Furthermore, the model should not be treated as a "black box"; the engineer or scientist must check model results to see if these results are reasonable.

4. This chapter is divided into five sections: Part II presents the governing equations and computational scheme used in the model, Part III defines the input data formats, Part IV discusses the model's input data requirements, and Part V contains several illustrative examples.

PART II: CLHYD MODEL FORMULATION

5. Time-dependent numerical models used to simulate long-period wave behavior in open coastal waters, estuaries, bays, and lakes have gained increasing acceptance as their accuracy has been demonstrated (Leendertse 1971). Both two- and three-dimensional numerical solutions of the governing partial differential equations are employed in long-wave applications. In two-dimensional models, the governing three-dimensional equations are integrated over the water depth to yield vertically averaged velocities, that is, velocities that are constant through the water column. This chapter documents the two-dimensional CLHYD model for simulating long-wave behavior (tidal circulation and storm surge propagation) in the horizontal plane in relatively shallow, well-mixed bodies of water. It should be noted, however, that without flooding and drying capabilities, storm surge applications may be questionable. These features will be incorporated in a later release of CLHYD.

Assumptions and Limitations

6. Proper application of the model requires a clear understanding of the physical processes occurring in a study area and a comprehension of the capabilities of the model to simulate those processes. The limitations of a model define its range of applicability. In particular, CLHYD is a two-dimensional depth-averaged model; therefore, the model should be applied only where the water column is well mixed and no significant vertical variations occur. Hydrostatic pressure conditions are assumed in the model formulation. Thus, the model should be applied only where there is no significant vertical acceleration of the water.

7. Applying CLHYD requires a clear understanding of the model's capabilities as well as its limitations. The model should be applied such that time and length scales associated with long-wave processes can be resolved. The minimum wavelength, L, that can be resolved is a function of the grid resolution and the water depth, H. The smallest wavelength that can be resolved is equal to twice the width of the smallest grid cell; however, long-wave models generally use much greater wavelength-to-grid-cell-width ratios. In addition, limitations imposed by shallow-water wave theory must be

valid for a problem under investigation. Shallow-water wave theory is valid only where the water depth is small in relation to the wavelength (H/L < 0.04). Therefore, the minimum wavelength must be greater than or equal to 25 times the deepest water depth.

8. Presently, the model lacks a flood/dry capability and cannot treat submerged or overtopping barriers. These features will be incorporated and released in a subsequent version of CLHYD. A thorough comprehension of the physical processes simulated by the model is necessary to ensure that the model is applied to appropriate problems, that it is applied correctly, and that accurate results are produced.

9. A discussion of the hydrodynamic equations used in CLHYD is provided in the following section. It is recommended that the reader refer to Horikawa (1988) for a detailed discussion of coastal hydrodynamics.

Governing Equations

10. The hydrodynamic equations used in CLHYD are derived from the classical Navier-Stokes equations formulated in a Cartesian coordinate system (Figure 6-1). If the vertical water accelerations are assumed to be small compared with the gravitational acceleration (hydrostatic pressure conditions exist) and the fluid is homogeneous, the depth-averaged approximation is appropriate and yields the following two-dimensional form of the governing equations:

$$\frac{\partial U}{\partial t} + \frac{\partial}{\partial x}\left(\frac{UU}{H}\right) + \frac{\partial}{\partial y}\left(\frac{UV}{H}\right) + gH\frac{\partial S}{\partial x} - fV - \frac{\tau_{Sx}}{\rho} + \frac{\tau_{Bx}}{\rho} + A_H\left(\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2}\right) = 0 \quad (1)$$

$$\frac{\partial V}{\partial t} + \frac{\partial}{\partial x}\left(\frac{UV}{H}\right) + \frac{\partial}{\partial y}\left(\frac{VV}{H}\right) + gH\frac{\partial S}{\partial y} + fU - \frac{\tau_{Sy}}{\rho} + \frac{\tau_{By}}{\rho} + A_H\left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2}\right) = 0 \quad (2)$$

$$\frac{\partial S}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0 \quad (3)$$

I II III IV V VI

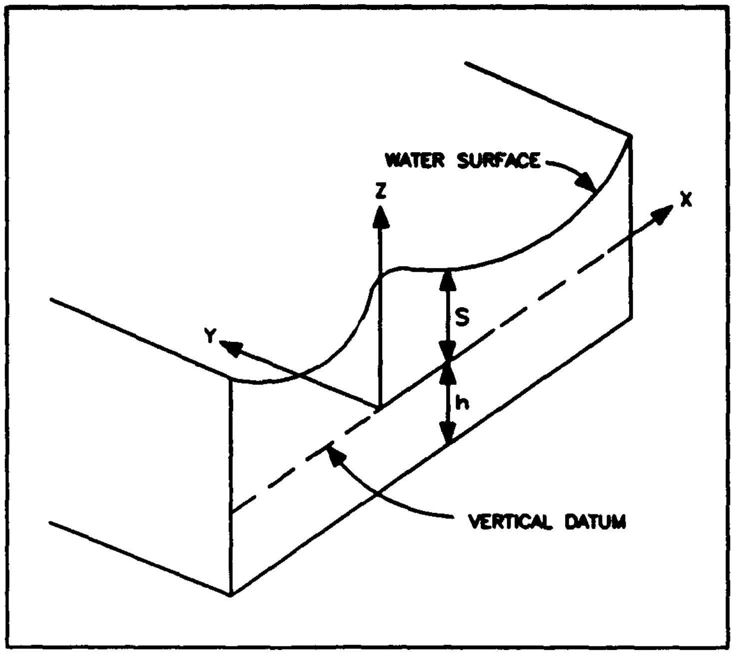

Figure 6-1. Definition sketch for Cartesian coordinate system

where

x, y, t	-	independent space and time variables
S	-	water surface displacement measured relative to an arbitrary datum
h	-	static water depth measured from the same datum
H	-	total water depth $(h+S)$
U, V	-	unit flow rate components in the x- and y-directions, respectively
τ_{Bx}, τ_{By}	-	bottom friction components in the x- and y-directions, respectively
f	-	Coriolis parameter
A_H	-	generalized dispersion coefficient
g	-	gravitational acceleration
τ_{sx}, τ_{sy}	-	external surface shear stresses, such as wind stress, in the x- and y-directions, respectively
ρ	-	fluid density (assumed to be constant)

Equations 6-1, 6-2, and 6-3 represent the x-momentum, y-momentum, and continuity equations, respectively.

11. A detailed discussion of the Navier-Stokes equations with a rigorous derivation of each term is found in Harris and Bodine (1977). A brief discussion of the physical significance of the six groups of terms in Equations 6-1 through 6-3 is given in Table 6-1 and below. The Roman numerals below correspond to the Roman numerals in Equations 6-1 through 6-3:

I. Local flow acceleration (i.e., local variation of momentum with respect to time).

II. Transport of momentum by advection (i.e., spatial acceleration).

III. Barotropic pressure forces and conservation of mass.

IV. Momentum sources and sinks due to Coriolis force and surface wind stress.

V. Momentum sink due to bed friction.

VI. Horizontal dispersion of momentum.

12. Various formulations of the terms in the governing equations are permissible. The expressions for bottom friction, dispersion, wind stress, and the Coriolis coefficient employed in CLHYD are given below:

<u>Bottom friction</u>

13. The bottom shear stress impeding fluid motion in unidirectional open channel flow can be expressed in terms of a quadratic (nonlinear) friction law (Dean and Dalrymple 1984):

$$\tau_B = \frac{\rho f u^2}{8} \tag{6-4}$$

where

ρ = fluid density

f = Darcy-Weisbach friction factor

u = fluid velocity

The importance of the direction of the velocity in oscillatory flow means that Equation 6-4 must contain an absolute value sign:

$$\tau_B = \frac{\rho f |u| u}{8} \tag{6-5}$$

Table 6-1

Description of Terms in the Governing Equations

Term	Definition and Discussion
$\frac{\partial U}{\partial t}, \frac{\partial V}{\partial t}$	Change of the vertically averaged flow per unit width with respect to time. Change may result from temporal acceleration of the mean flow.
$gH\frac{\partial S}{\partial x}, gH\frac{\partial S}{\partial y}$	Pressure gradient terms; describes the slope of the water surface; principal driving force of fluid flow.
τ_{Bx}, τ_{By}	Bottom friction terms; stress of the fluid layer against the bottom boundary; serves as an energy dissipator.
fU, fV	Coriolis terms; accounts for the effect of the Earth's rotation.
$\frac{\partial}{\partial x}\left(\frac{UU}{H}\right)$	Advective (inertia) terms; describes the movement of water due to the fluid motion itself.
τ_{sx}, τ_{sy}	External shear stresses (such as the wind); any forcing function that serves to drive the fluid motion.
$A_H\left(\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2}\right)$	Horizontal dispersion of momentum; describes the dispersion of momentum due to fluid motion; A_H is sometimes referred to as the eddy viscosity.
$\frac{\partial S}{\partial t}$	Change in water level with respect to time.
$\frac{\partial U}{\partial x}, \frac{\partial U}{\partial y}$	Rate at which water is converging or diverging horizontally at a given point (x,y) in space.

14. CLHYD uses the following quadratic expression to represent the bottom shear stress in the x-momentum equation:

$$\tau_{Bx} = \frac{g}{C_z^2 H^2} \sqrt{U^2 + V^2}\, U \tag{6-6}$$

where

g = gravitational acceleration

C_z = Chezy's friction coefficient

H = water depth

U, V = unit flow rate components in the x- and y-directions, respectively

A similar expression is used for τ_{By} in the y-momentum equation.

15. Rather than specifying the Chezy coefficient, Manning's n, which is a function of depth, is often prescribed (Chow 1959). The two coefficients are related through the following equation:

$$C_z = \frac{H^{1/6}}{n}$$

CLHYD uses a spatially variable Manning's coefficient. The advantage of a spatially variable friction coefficient is that variation in depth and bottom roughness can be factored into the bottom shear stress computations.

Dispersion coefficient

16. The dispersion coefficient, A_H, is treated as a constant in CLHYD and describes the rate of dispersion of momentum due to the fluid motion. A_H is a function of the grid spacing and may take a value of 100 m^2/sec or more for a grid spacing of several kilometers. Due to the current representation of the advective terms in CLHYD, results are not extremely sensitive to A_H.

Wind stress coefficient

17. The wind stress, τ_s, is formulated as:

$$\tau_s = C_D |W| W \tag{6-8}$$

where W is the wind velocity, C_D is the wind drag coefficient determined from Garratt's equation (Garratt 1977):

$$C_D = \frac{(0.75 + 0.067\omega)}{1000}\,, \tag{6-9}$$

and ω is the resultant wind speed (meters/second).

Coriolis coefficient

18. The Coriolis term accounts for the fact that the Earth is rotating, whereas the coordinate frame of our computations is fixed. The Coriolis parameter, f , is expressed as:

$$f = 2\nu \sin\lambda \tag{6-10}$$

where ν is the angular speed of the Earth's rotation (7.292 x 10^{-5} rad/sec) and λ is the latitude of the study area.

19. This completes the basic model formulation. If further details are desired, the reader should refer to Roache (1976) or Horikawa (1988).

Grid Systems

20. The governing equations (Equations 6-1, 6-2, and 6-3), which describe the physical processes associated with shallow-water wave motion, contain partial derivatives with respect to time and space. Model CLHYD uses mathematical (finite difference) approximations to represent these continuous equations. The continuum is, therefore, represented by discrete points in time and space. The discretization of the horizontal plane is accomplished via a computational grid composed of a lattice network of cells. Each cell has certain flow field parameters associated with it. In the case of the model CLHYD, the water surface elevation is defined at the center of each cell and the unit flow rate components are defined on the cell faces. All information required as input to the model, including water depths and external forces (such as wind), is also defined at each cell.

21. CLHYD is capable of using a uniform Cartesian grid, a stretched Cartesian grid, or a general curvilinear grid (Figures 6-2 through 6-4). Each successive type of grid can provide a more accurate representation of an area; however, the complexity of the governing equations increases with each successive grid type.

22. Uniform Cartesian grids simply have cells of equal size in the x-direction and equal size in the y-direction. The advantages of using a uniform Cartesian grid are: (a) the simplicity of generating a grid; (b) the simplicity of formulating the governing equations; (c) there are fewer terms

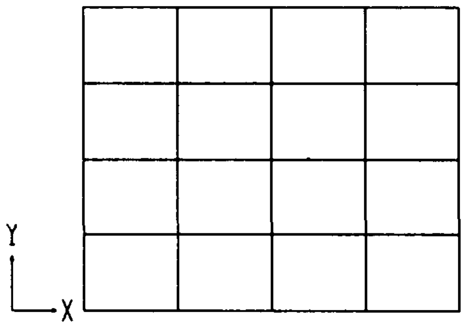

Figure 6-2. Uniform Cartesian grid

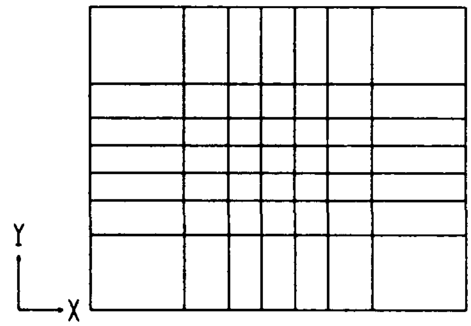

Figure 6-3. Stretched Cartesian grid

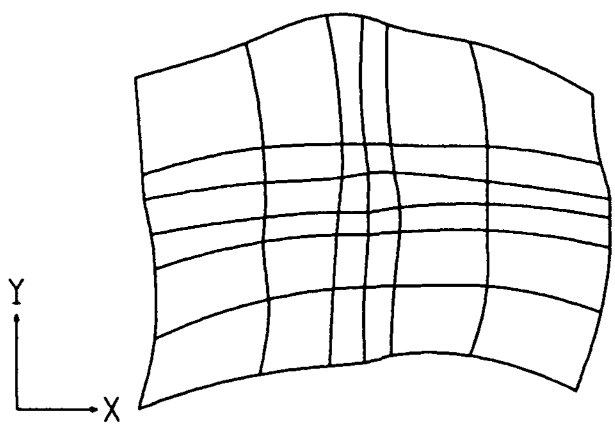

Figure 6-4. General curvilinear grid

in the governing equations, and therefore, the computational requirements are minimized; and (d) uniform grids have been widely used and thoroughly tested. The disadvantages of using a uniform Cartesian grid include: (a) they lack the ability to increase grid resolution in areas of interest; (b) consequently, it is usually uneconomical to use a fine-resolution grid throughout an entire area; and (c) they cannot efficiently resolve an irregular shoreline and therefore require "stair-stepping," which can lead to computational inaccuracies (Weare 1979).

23. Stretched Cartesian grids are flexible enough to increase grid resolution and, therefore, provide a more economical representation of an area than a uniform Cartesian grid. In other words, the number of grid cells required to represent an area can be reduced by using a stretched grid, which in turn reduces computational costs. However, one must also consider that the

number of terms in the governing equations increases when going from a uniform to a stretched grid.

24. Neither the uniform nor the stretched Cartesian grids can accurately depict irregular shorelines and must therefore resort to "stair-stepping." However, nonorthogonal curvilinear (boundary-fitted) grids can be made to conform to bathymetric features and provide an accurate means of representing a study area (Figure 6-4). These grids can be generated using a numerical grid generator such as program EAGLE (Thompson 1985), which has the flexibility to concentrate grid lines in shallow/deep areas or in areas where the bathymetric gradients are great. With the increase in accuracy and adaptability comes increased complexity of the governing equations and the associated computational costs. In addition, general curvilinear grids are complex networks and are therefore more difficult to generate. However, the increased accuracy and adaptability are often necessary to adequately represent features in coastal areas.

25. For areas having irregular geometries, model CLHYD is capable of using a nonorthogonal curvilinear grid. Thompson (1983) developed a method for generating two-dimensional boundary-fitted grids by solving elliptic equations. These equations relate the nonorthogonal curvilinear coordinate system in the physical plane (x,y) with a uniformly spaced coordinate system in the transformed plane (ξ,η) (Figure 6-5). The elliptic equations are:

$$\xi_{xx} + \xi_{yy} = P \tag{6-11}$$

$$\eta_{xx} + \eta_{yy} = Q \tag{6-12}$$

with the following boundary conditions:

$$\left.\begin{array}{l}\xi = \xi(x,y) \\ \eta = constant\end{array}\right\} \quad on\ north\ and\ south\ boundaries$$

$$\left.\begin{array}{l}\xi = constant \\ \eta = \eta(x,y)\end{array}\right\} \quad on\ east\ and\ west\ boundaries$$

where the functions P and Q may be chosen to obtain the desired grid resolution and alignment.

26. When using a nonorthogonal curvilinear grid, the governing equations must be transformed into curvilinear coordinates. A straightforward

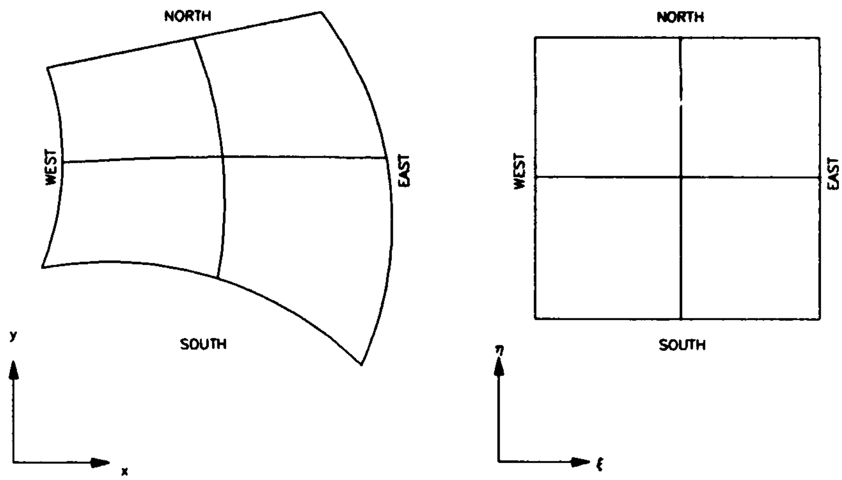

Figure 6-5. Physical and transformed planes

method is to transform only the dependent variables (x,y) and then solve for the Cartesian components of the velocity and water surface displacement Johnson 1982). The advantage of this method is its simplicity in generating the transformed equations via the chain rule; although the resulting equations are quite complex. Disadvantages are: (a) the boundary conditions are complicated because the Cartesian velocity components are generally not aligned with the grid lines; (b) a staggered grid (i.e., a grid in which values of velocity and water surface elevation are defined at different points) cannot be readily used; and (c) numerical instabilities may develop (Sheng 1986).

27. To avoid these problems, Sheng transformed the dependent (S,U,V) as well as the independent variables (x,y). Vector quantities (e.g., U,V) are transformed by multiplying the vector by a scale factor. Scalar quantities (e.g., S) in the physical plane are the same in the transformed plane; however, the spatial derivatives require transformation via scale factors. Equations in the transformed plane (ξ,η) can be obtained in terms of the contravariant, covariant, or physical velocity components via coordinate transformations (Thompson 1985). Sheng recommended use of contravariant components. Contravariant components ($\underline{a}^1$, $\underline{a}^2$, $\underline{a}^3$) are normal to coordinate planes, and covariant components ($\underline{a}_1$, $\underline{a}_2$, $\underline{a}_3$) are tangential to coordinate lines (Figure 6-6). The three components are identical in a uniform cartesian coordinate system with square grid cells, but differ for other systems. Model

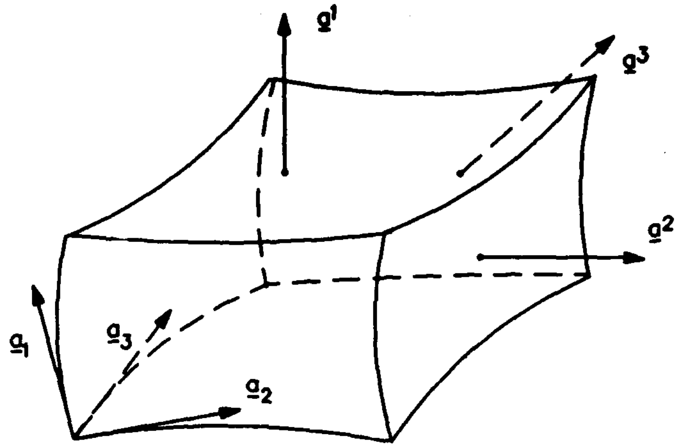

Figure 6-6. Covariant and contravariant components

CLHYD employs contravariant components in the transformation of the governing equations.

28. The flow rate components in physical space (i.e., $U(i)$ and $V(j)$) are related to the contravariant components (i.e., U^i, V^i, U^j, V^j) by the following equations:

$$U(i) = \frac{g_{11}}{|g|} U^i + \frac{g_{12}}{|g|} V^i \tag{6-13}$$

$$V(j) = \frac{g_{21}}{|g|} U^j + \frac{g_{22}}{|g|} V^j \tag{6-14}$$

where:

$$g_{ij} = \begin{bmatrix} x_\xi^2 + y_\xi^2 & x_\xi x_\eta + y_\xi y_\eta \\ x_\eta x_\xi + y_\eta y_\xi & x_\eta^2 + y_\eta^2 \end{bmatrix} \tag{6-15}$$

or

$$g_{ij} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \tag{6-16}$$

and $|g|$ is the determinant of the metric tensor g_{ij}:

$$|g| = g_{11}g_{22} - g_{12}g_{21} \tag{6-17}$$

The surface slope terms are transformed as follows:

$$\frac{\partial S}{\partial x} = g^{11}\frac{\partial S}{\partial \xi} + g^{12}\frac{\partial S}{\partial \eta} \tag{6-18}$$

$$\frac{\partial S}{\partial y} = g^{21}\frac{\partial S}{\partial \xi} + g^{22}\frac{\partial S}{\partial \eta} \tag{6-19}$$

where g^{ij} are inverse metric tensor components:

$$g^{ij} = \frac{1}{|g|}\begin{bmatrix} x_\eta^2 + y_\eta^2 & -(x_\eta x_\xi + y_\eta y_\xi) \\ -(x_\xi x_\eta + y_\xi y_\eta) & x_\xi^2 + y_\xi^2 \end{bmatrix} = \frac{1}{|g|}\begin{bmatrix} g_{22} & -g_{21} \\ -g_{12} & g_{11} \end{bmatrix} \tag{6-20}$$

or

$$g^{ij} = \begin{bmatrix} g^{11} & g^{12} \\ g^{21} & g^{22} \end{bmatrix} \tag{6-21}$$

For details of these transformations, the reader is referred to Thompson (1985).

Governing Equations in General Curvilinear Coordinates

29. The transformed governing equations developed by Sheng (1985) are as follows:

ξ-Momentum

$$\frac{\partial U}{\partial t} + Inertia^* + gH\left(g^{11}\frac{\partial S}{\partial \xi} + g^{12}\frac{\partial S}{\partial \eta}\right) - \frac{g_{12}}{|g_u|}fU - \frac{g_{22}}{|g_u|}f\bar{\bar{V}} - \frac{\tau_{s\xi}}{\rho} \tag{6-22}$$

$$+ \frac{g(g_{11}U^2 + 2g_{12}U\bar{\bar{V}} + g_{22}\bar{\bar{V}}^2)^{1/2}}{C_z^2H^2}U + Diffusion^* = 0$$

η-Momentum

$$\frac{\partial V}{\partial t} + Inertia^* + gH\left(g^{21}\frac{\partial S}{\partial \xi} + g^{22}\frac{\partial S}{\partial \eta}\right) + \frac{g_{11}}{|g_v|}f\bar{\bar{U}} + \frac{g_{12}}{|g_v|}fV - \frac{\tau_{\eta}}{\rho} \qquad (6\text{-}23)$$

$$+ g\frac{(g_{11}\bar{\bar{U}}^2 + 2g_{12}\bar{\bar{U}}V + g_{22}V^2)^{1/2}}{C_z^2H^2}V + Diffusion^* = 0$$

Continuity

$$\frac{\partial S}{\partial t} + \frac{1}{|g_s|}\frac{\partial}{\partial \xi}(|g_u|U) + \frac{1}{|g_s|}\frac{\partial}{d\eta}(|g_v|V) = 0 \qquad (6\text{-}24)$$

where

U,V = contravariant unit flow rate components in the transformed plane (superscripts have been dropped for convenience)

g^{ij} = inverse metric tensor components

g_{ij} = metric tensor components

$|g_s|$ = determinant of the metric tensor, $|g|$, at an S-point**

$|g_u|$ = determinant of the metric tensor, $|g|$, at an U-face**

$|g_v|$ = determinant of the metric tensor, $|g|$, at an V-face**

$\bar{\bar{U}}$ = average x-direction unit flow rate at a V-face**

$\bar{\bar{V}}$ = average y-direction unit flow rate at a U-face**

* Inertia and dispersion terms are given in Appendix 6-A

** S-, U-, V-points are defined in Figure 6-7

Finite Difference Methods

30. Although analytic solutions of the governing equations exist for simple situations, they do not exist for situations generally encountered in the field. Therefore, it is necessary to use numerical approximations of the governing equations to produce a general purpose model. This can be accomplished by representing the derivatives presented in Equations 6-22 through 6-24 with finite difference approximations.

31. In the finite difference approach, the continuous problem domain is discretized so that dependent variables are defined only at discrete points. Derivatives are approximated by differences resulting in an algebraic problem.

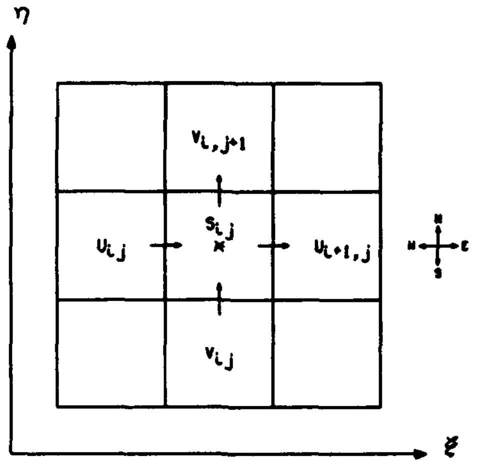

Figure 6-7. Definition of variable positions

Several factors determine whether the solution obtained is a good approximation to the exact solution of the original partial differential equation (PDE) including: truncation error, numerical stability, round-off error, and discretization error. These factors will be discussed later in this section.

32. As was previously mentioned, the continuous problem domain is represented with a finite difference grid in the (x,y) or (ξ,η) plane (Figure 6-8). It should be noted that the (x,y) and (ξ,η) planes can be used interchangeably here. The (x,y) plane is used merely for explanation purposes. If a variable $a(x,y)$ is defined at each point on the grid as $a(i\Delta x, j\Delta y)$, then a difference equation can be written in terms of the general point (i,j) and its neighboring points:

$$a_{ij} = a(x,y) \qquad a_{i+1,j} = a(x+\Delta x,y) \qquad a_{i,j+1} = a(x,y+\Delta y)$$
$$a_{i-1,j} = a(x-\Delta x,y) \qquad a_{i,j-1} = a(x,y-\Delta y)$$

33. Recall that the definition of the derivative of a function $a(x,y)$ at a point $(x = x_o,\ y = y_o)$ is given by:

$$\left.\frac{\partial a}{\partial x}\right|_{x_o y_o} = \lim_{\Delta x \to 0} \frac{a(x_o+\Delta x, y_o) - a(x_o, y_o)}{\Delta x} \qquad (6\text{-}25)$$

This approximation improves as Δx decreases. Developing a Taylor series expansion for $a(x+\Delta x,y)$ about (x_o,y_o) yields:

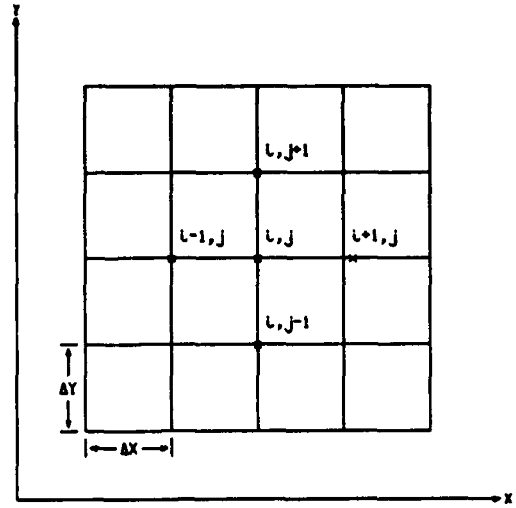

Figure 6-8. Finite difference grid

$$a(x_o+\Delta x, y_o) = a(x_o, y_o) + \left.\frac{\partial a}{\partial x}\right|_{x_o y_o} \Delta x + \left.\frac{\partial^2 a}{\partial x^2}\right|_{x_o y_o} \frac{(\Delta x)^2}{2!} + H.O.T. \qquad (6\text{-}26)$$

where H.O.T. signifies Higher Order Terms.

A forward difference is formed by rearranging Equations 6-26:

$$\left.\frac{\partial a}{\partial x}\right|_{x_o y_o} = \frac{a(x_o+\Delta x, y_o) - a(x_o, y_o)}{\Delta x} - \left.\frac{\partial^2 a}{\partial x^2}\right|_{x_o y_o} \frac{(\Delta x)}{2!} + H.O.T. \qquad (6\text{-}27)$$

or by simply using the (i,j) notation, the following is obtained:

$$\left.\frac{\partial a}{\partial x}\right|_{i,j} = \frac{a_{i+1,j} - a_{i,j}}{\Delta x} + O(\Delta x) \qquad (6\text{-}28)$$

where $O(\Delta x)$ is used to indicate terms of order Δx. The backwards difference can be obtained similarly as:

$$\left.\frac{\partial a}{\partial x}\right|_{i,j} = \frac{a_{i,j} - a_{i-1,j}}{\Delta x} + O(\Delta x) \qquad (6\text{-}29)$$

The central difference representation is as follows:

$$\left.\frac{\partial a}{\partial x}\right|_{i,j} = \frac{a_{i+1,j} - a_{i-1,j}}{2\Delta x} + O(\Delta x)^2 \qquad (6\text{-}30)$$

These are only a few examples of the ways in which derivatives can be approximated. Primarily central differences are used to approximate spatial derivatives in the formulation of CLHYD.

34. The accuracy of these approximations is dependent on a number of factors. Round-off error is inherent to repetitive computations that are rounded to a finite number of digits, such as the continual solution of the finite difference equations in CLHYD, by a computer. Truncation error is defined as the difference between the PDE and the difference approximation. A finite difference representation is said to be consistent if the truncation error vanishes as the grid is refined. A more difficult problem is ensuring that the solution scheme is stable. A stable scheme does not permit errors, such as truncation or round-off to grow as the calculations proceed from one time-step to another. Discretization error is the error in the solution to the PDE caused by replacing the continuous problem by a discrete one, and it is defined as the difference between the exact solution of the PDE and the exact solution to the finite difference equation. In other words, it is the sum of the truncation error and any errors introduced by the treatment of the boundary conditions.

35. The finite difference approximations incorporated into CLHYD are based on an Eulerian system where the velocities and water surface fluctuations are computed at discrete locations within the flow field. A network of grid cells is used to define the parameter locations. A representative grid cell in computational space (ξ,η) is shown in Figure 6-7. In this staggered grid, the water surface fluctuation is defined at the cell center (i,j) , ξ-direction unit flow rates (U) are defined at the "west" (i,j) and "east" $(i+1,j)$ cell faces, and the η-direction unit flow rates (V) are computed at the "south" (i,j) and "north" $(i,j+1)$ cell faces. The finite difference approximations of the governing equations follow. Note that the continuity equation is split into two parts (Equations 6-33 and 6-34) to be used in the solution scheme described in paragraph 36. The sum of these equations is the one original continuity equation.

ξ-Momentum

$$\frac{U^*_{i,j} - U^n_{i,j}}{\Delta t} + I^n_{i,j} + \theta g H g^{11}\left(\frac{S^*_{i,j} - S^*_{i-1,j}}{\Delta \xi}\right) + \tag{6-31}$$

$$(1-\theta)\, g H g^{11}\left(\frac{S^n_{i,j} - S^n_{i-1,j}}{\Delta \xi}\right) + g H g^{12}\left(\frac{S^n_{i-1/2,j+1/2} - S^n_{i-1/2,j-1/2}}{\Delta \eta}\right) -$$

$$\frac{g_{12}}{|g_u|} f U^n_{i,j} - \frac{g_{22}}{|g_u|} f \bar{\bar{V}} - \frac{\tau_{s\xi}}{\rho} + \theta (FRIC)\, U^*_{i,j} + (1-\theta)\,(FRIC)\, U^n_{i,j} + D^n_{i,j} = 0$$

where

n - previous time level

$*$ - intermediate time level

$n+1$ - solve for this time level

θ - weighting factor between successive time levels

I - inertia

D - dispersion

and

$$FRIC = \frac{g}{C_s^2 H^2}\left(g_{11} U^2_{i,j} + 2 g_{12} U_{i,j} \bar{\bar{V}} + g_{22} \bar{\bar{V}}^2\right)^{1/2}$$

evaluated at time level n

Finite difference forms of the inertia and dispersion terms are given in Appendix 6-A.

η-Momentum

$$\frac{V^{n+1}_{i,j} - V^n_{i,j}}{\Delta t} + I^n_{i,j} + g H g^{21}\left(\frac{S^n_{i+1/2,j-1/2} - S^n_{i-1/2,j-1/2}}{\Delta \xi}\right) + \tag{6-32}$$

$$\theta g H g^{22}\left(\frac{S^{n+1}_{i,j} - S^{n+1}_{i,j-1}}{\Delta \eta}\right) + (1-\theta)\, g H g^{22}\left(\frac{S^n_{i,j} - S^n_{i,j-1}}{\Delta \eta}\right) + \frac{g_{11}}{|g_v|} f \bar{\bar{U}} +$$

$$\frac{g_{12}}{|g_v|} f V^n_{i,j} - \frac{\tau_{s\eta}}{\rho} + \theta (FRIC)\, V^{n+1}_{i,j} + (1-\theta)\,(FRIC)\, V^n_{i,j} + D^n_{i,j} = 0$$

ξ-Continuity

$$\frac{S^{*}_{i,j} - S^{n}_{i,j}}{\Delta t} + \theta\frac{|g_u|}{|g_s|}\left(\frac{U^{*}_{i+1,j} - U^{*}_{i,j}}{\Delta\xi}\right) + (1-\theta)\frac{|g_u|}{|g_s|}\left(\frac{U^{n}_{i+1,j} - U^{n}_{i,j}}{\Delta\xi}\right) + \tag{6-33}$$

$$\frac{|g_v|}{|g_s|}\left(\frac{V^{n}_{i,j+1} - V^{n}_{i,j}}{\Delta\eta}\right) = 0$$

η-Continuity

$$\frac{S^{n+1}_{i,j} - S^{*}_{i,j}}{\Delta t} + \theta\frac{|g_v|}{|g_s|}\left(\frac{V^{n+1}_{i,j+1} - V^{n+1}_{i,j}}{\Delta\eta}\right) + (1-\theta)\frac{1Feg_v|}{|g_s|}\left(\frac{V^{n}_{i,j+1} - V^{n}_{i,j}}{\Delta\eta}\right) - \tag{6-34}$$

$$\frac{|g_v|}{|g_s|}\left(\frac{V^{n}_{i,j+1} - V^{n}_{i,j}}{\Delta\eta}\right) = 0$$

Rearranging the terms in Equations 6-31 through 6-34 yields:

ξ-Momentum

$$\theta\left(-gHg^{11}\frac{\Delta t}{\Delta\xi}\right)S^{*}_{i-1,j} + (1 + \theta(FRIC)\Delta t)\,U^{*}_{i,j} + \theta\left(gHg^{11}\frac{\Delta t}{\Delta\xi}\right)S^{*}_{i,j} = B_4 \tag{6-35}$$

B$_1$ B$_2$ B$_3$

where: B_4 represents all known quantities

η-Momentum

$$\theta\left(-gHg^{22}\frac{\Delta t}{\Delta\eta}\right)S^{n+1}_{i,j-1} + (1 + \theta(FRIC)\Delta t)\,V^{n+1}_{i,j} + \theta\left(gHg^{22}\frac{\Delta t}{\Delta\eta}\right)S^{n+1}_{i,j} = B_4 \tag{6-36}$$

B$_1$ B$_2$ B$_3$

ξ-Continuity

$$\theta\left(\frac{-|g_u|}{|g_s|}\frac{\Delta t}{\Delta\xi}\right)U^{*}_{i,j} + [1]\,S^{*}_{i,j} + \theta\left(\frac{|g_u|}{|g_s|}\frac{\Delta t}{\Delta\xi}\right)U^{*}_{i+1,j} = A_4 \tag{6-37}$$

A$_1$ A$_2$ A$_3$

where: A_4 represents all known quantities

η-Continuity

$$\theta\left(\frac{-|g_v|}{|g_e|}\frac{\Delta t}{\Delta\eta}\right)V^{n+1}_{i,j} + [1]\,S^{n+1}_{i,j} + \theta\left(\frac{|g_v|}{|g_e|}\frac{\Delta t}{\Delta\eta}\right)V^{n+1}_{i,j+1} = A_4 \qquad (6\text{-}38)$$

A_1 $\qquad$ A_2 $\qquad$ A_3

Computational Theory

36. The computational procedure used in CLHYD is based on an Alternating Direction Implicit (ADI) scheme (Roache 1976). Using this method, the ξ- and η-momentum equations are solved separately, and each calculation in time is made in two stages (Figure 6-9). In the first stage, the ξ-continuity and ξ-momentum equations are solved along each row of the grid to progress from time level n to an intermediate time level $*$. The ξ-direction unit flow rate components and water surface fluctuations are solved implicitly, and the η-direction unit flow rate components are supplied from time level n. The ξ-direction unit flow rates from this step represent those at time level $n+1$, whereas the water surface fluctuations are only an approximation to those at time level $n+1$. The η-direction unit flow rate components remain at time level n. In the second stage, the η-continuity and η-momentum equations are solved along each column for the η-direction unit flow rates and the water surface fluctuations at time level $n+1$. ξ-direction unit flow rate components are supplied from the first stage calculations.

37. As shown in the finite difference approximations to the governing equations, a weighting factor, θ, is used to place the water surface slope and bottom friction terms between time levels n and $n+1$. When the weighting factor equals 0.0, these terms are evaluated at the previous time level n (explicit treatment), whereas when the weighting factor equals 1.0, they are evaluated at the new time level $n+1$ (implicit treatment). Usually a value between 0.0 and 1.0 is used. Tests have shown that a value of 0.55 produces a stable solution with less damping of the solution than occurs with a value of 1.0.

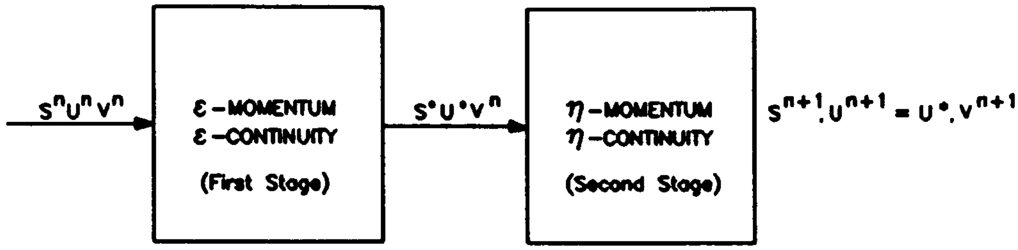

Figure 6-9. Computational procedure for ADI scheme

<u>Tridiagonal matrix</u>

38. As was mentioned earlier, the ξ-direction continuity and momentum and the η-direction continuity and momentum equations are solved separately. For a given segment (Figure 6-10), the ξ-continuity and ξ-momentum equations are alternately solved at *S*- and *U*-points, respectively. Similarly, the η-continuity and η-momentum equations are alternately solved at *S*- and *V*-points.

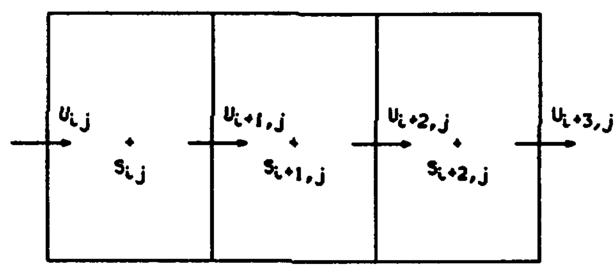

Figure 6-10. ξ-sweep solution segment.

The equations corresponding to Figure 6-10 are:

$$
\begin{array}{ll}
\text{C:} & A_{1i}U_{ij} + A_{2i}S_{ij} + A_{3i}U_{i+1,j} = A_{4i} \\
\text{M:} & B_{1,i+1}S_{ij} + B_{2,i+1}U_{i+1,j} + B_{3,i+1}S_{i+1,j} = B_{4,i+1} \\
\text{C:} & A_{1,i+1}U_{i+1,j} + A_{2,i+1}S_{i+1,j} + A_{3,i+1}U_{i+2,j} = A_{4,i+1} \\
\text{M:} & B_{1,i+2}S_{i+1,j} + B_{2,i+2}U_{i+2,j} + B_{3,i+2}S_{i+2,j} = B_{4,i+2} \\
\text{C:} & A_{1,i+2}U_{i+2,j} + A_{2,i+2}S_{i+2,j} + A_{3,i+2}U_{i+3,j} = A_{4,i+2}
\end{array}
$$

where *C:* indicates the x-continuity equation and *M:* indicates the x-momentum equation, or in matrix form:

$$\begin{bmatrix} A_{2,i} & A_{3,i} & 0 & 0 & 0 \\ B_{1,i+1} & B_{2,i+1} & B_{3,i+1} & 0 & 0 \\ 0 & A_{1,i+1} & A_{2,i+1} & A_{3,i+1} & 0 \\ 0 & 0 & B_{1,i+2} & B_{2,i+2} & B_{3,i+2} \\ 0 & 0 & 0 & A_{1,i+2} & A_{2,i+2} \end{bmatrix} \begin{bmatrix} S_{i,j} \\ U_{i+1,j} \\ S_{i+1,j} \\ U_{i+2,j} \\ S_{i+2,j} \end{bmatrix} = \begin{bmatrix} A_{4,i} - A_{1,i} U_{i,j} \\ B_{4,i+1} \\ A_{4,i+1} \\ B_{4,i+2} \\ A_{4,i+2} - A_{3,i+2} U_{i+3,j} \end{bmatrix}$$

This system of equations is in the form of a banded or tridiagonal matrix and is solved using the Thomas (1949) algorithm (Gaussian elimination and back substitution procedures).

39. In the Gaussian elimination step, all lower diagonal elements (A_1's and B_1's) are eliminated and are incorporated into other matrix elements. The system of equations is thus reduced to an upper diagonal matrix with only two unknowns per equation. The back substitution sweep then involves the solution of the system of equations for all variables, U_i and S_i .

Boundary conditions

40. The matrix equation previously shown contains *N-2* simultaneous equations containing *N* unknowns. The boundary conditions provide the remaining information needed to solve the system of equations. The boundary conditions are classified into three general categories: open boundaries, land-water boundaries, and subgrid barriers.

Open boundaries

41. Boundaries classified as open include: a seaward edge of a computational grid defined as water, or a channel (river) that flows across any boundary. Water surface (tide) levels or unit flow (river flow) rates can be specified along an open boundary as functions of time. An open boundary can also be specified with a uniform flux (zero gradient) boundary condition. Research has been conducted to add a radiation boundary condition option, which relates water levels and flow rates, into the model. This option will be incorporated in a later release of CLHYD.

Tidal boundary

42. A tidal boundary condition (TBC) allows for fluctuations in the free surface and is, therefore, applied at an *S*-point (Figure 6-11). The computations proceed from the first internal *U*-face to the last *S*-point. For

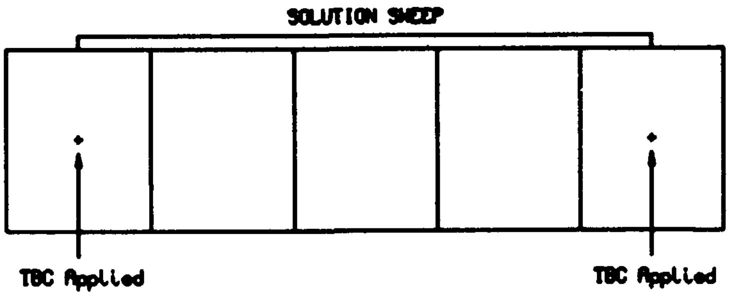

Figure 6-11. Tidal boundary condition (TBC)

the case of a tidal boundary on the west (or south), a special formulation of the momentum equation at the next internal U-face is required:

$$B_{2,i+1}U_{i+1,j} + B_{3,i+1}S_{i+1,j} = B_{4,i+1} - B_{1,i+1}S_{i,j} \tag{6-39}$$

The sweep proceeds from this U-point to the easternmost S-point.

43. For a tidal boundary on the east (or north), a special formulation of the momentum equation at the last internal U-face is required:

$$B_{1,imax}S_{imax-1,j} + B_{2,imax}U_{imax,j} = B_{4,imax} - B_{3,imax}S_{imax,j} \tag{6-40}$$

The sweep proceeds from the westernmost S-point to this U-point.

River boundary

44. A river boundary condition (RBC) allows flow into or out of a computational grid. Being a flow condition, the river boundary condition is applied at a U- or V-face (Figure 6-12). The solution proceeds from the next internal S-point to the last S-point. For a river boundary on a west (or south) boundary a special formulation of the A_1 in the continuity equation at the first S-point is required:

$$A_{2i}S_{i,j} + A_{3i}U_{i+1,j} = A_{4i} - A_{1i}U_i \tag{6-41}$$

The sweep proceeds from this S-point to the last S-point.

45. For a river boundary on an east (or north) boundary, a special formulation of the A_1 in the continuity equation at the last S-point is required:

$$A_{1,imax}U_{imax,j} + A_{2,imax}S_{imax,j} = A_{4,imax} - A_{3,imax}U_{imax+1,j} \tag{6-42}$$

The sweep proceeds from the first S-point to this last S-point.

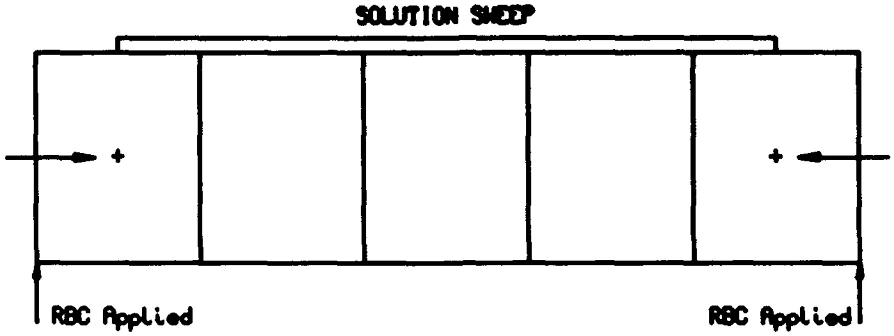

Figure 6-12. River boundary condition (RBC)

Uniform flux boundary condition

46. A uniform flux (or zero gradient) boundary condition (UFBC) implies that flow is constant across such a boundary. Similar to a river boundary, the UFBC is applied at a U- or V-face, and the solution begins at the next internal S-point (Figure 6-13). For a UFBC on a west (or south) boundary, a special formulation of the A_i in the continuity equation at the first S-point is required:

$$A_{2i}S_{i,j} + (A_{1i} + A_{3i})\,U_{i+1,j} = A_{4i} \tag{6-43}$$

The sweep proceeds from this S-point to the last S-point.

47. For a UFBC on an east (or north) boundary, a formulation of the A_i in the continuity equation at the last S-point is required:

$$(A_{1,imax} + A_{3,imax})\,U_{imax,j} + A_{2,imax}S_{imax,j} = A_{4,imax} \tag{6-44}$$

The sweep proceeds from the first S-point to this last S-point.

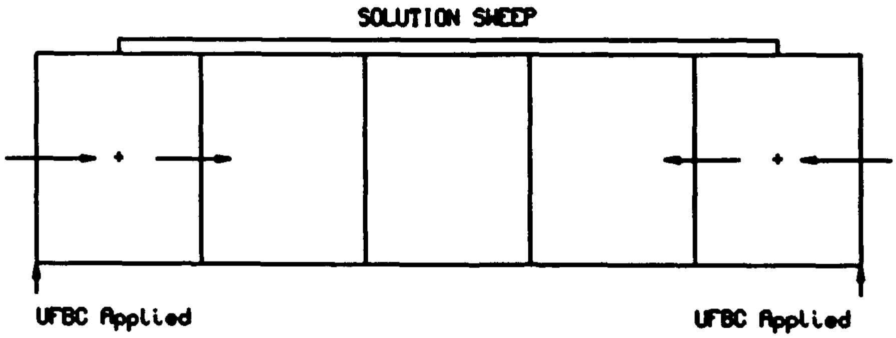

Figure 6-13. Uniform flux boundary condition (UFBC)

Land-water boundaries

48. With land-water boundaries (i.e., the coastline), water velocities normal to the land-water interfaces are set equal to zero in the CLHYD model. This condition means that the boundary is closed and no flow is permitted across such a boundary. Therefore, this model lacks the capability to simulate flooding and drying of low-lying areas. This capability will be added with a future release of CLHYD.

49. A land-water (closed) boundary is applied at a *U*- or *V*-face, and the solution begins at the next internal *S*-point. For a land-water boundary on a west (or south) boundary, a special formulation of the A_i in the continuity equation at the first *S*-point is required.

$$A_{2i}S_{i,j} + A_{3i}U_{i+1,j} = A_{4i} \tag{6-45}$$

The sweep proceeds from this *S*-point to the last *S*-point.

50. For a land-water boundary on an east (or north) boundary, a special formulation of the A_i in the continuity equation at the last *S*-point is required:

$$A_{1,imax}U_{imax,j} + A_{2,imax}S_{imax,j} = A_{4,imax} \tag{6-46}$$

The sweep proceeds from the first *S*-point to this last *S*-point.

Subgrid barriers

51. Subgrid barriers (e.g., breakwaters) are treated as thin, impermeable walls that extend above the water surface, preventing flow from one cell to the next. These exposed barriers are defined along specified interior cell faces and can be used to represent any nonovertopping structure in a study area. They can also be used to represent small islands when using a coarse grid. A subsequent release of CLHYD will include submerged and overtopping barriers.

PART III: DEFINITION OF INPUT DATA FORMAT

52. The input data set format was designed to resemble the format required by the series of models released by the USAE Hydrologic Engineering Center. It is the intent that this structure, being familiar to Corps personnel, will reduce the time needed to learn this system. The general format of the input data set records, where a record refers to one line of data, is presented below:

a. Each record is divided into 10 fields containing 8 columns each.

b. Field 1 (i.e., columns 1 through 8) contains a mnemonic identification label that describes the purpose or function of each record.

c. Fields 2 through 10 contain data that may be real, integer, or character in type. Integers must be right justified. Real numbers must also be right-justified if the decimal point is omitted. Character data do not need to be right- or left-justified.

d. Array data, such as depths, are read with DO or Implied DO loops. No label is required for each record containing array data. However, a general specification record, such as BATHSPEC, which defines bathymetric attributes, must precede that array.

53. Spelling of record identification labels and alphanumeric variables is important. Misspelled entries will result in either recognized error conditions that force the model to abort execution or bypassing of desired user-defined operations, such as saving time-history data.

54. Certain records and variables have been assigned default values in the model for minimizing input data and computer resources. Thus, not all input data records will be needed for each application, and only those records pertinent to the sim . tion or required by the model should be included. Default values are representative of those chosen in previous studies performed by CERC. Although these quantities may not be applicable to all studies, they can serve as a guide when selecting alternative values.

55. Default values are processed when the record field corresponding to that variable is blank. Hence, the user must be careful when leaving fields blank in a record; blank fields will not necessarily result in a variable

being assigned a value of zero. These variables and their respective default values are noted in Appendix 6-B. The following discussion pertains to the general format of the input records given in Appendix 6-B.

56. Each record is presented in a standardized tabular format and has as its heading the mnemonic identification label or name with a brief description of its function. Following its name, the record has an abbreviated note documenting whether it is required for a simulation. These abbreviations have the following definitions.

(Req)	Record or variable is required for each simulation.
(Opt)	Record or variable is optional. Omitting this item results in either the default value being used or the defined operation not being performed.
(C-opt)	Record or variable is required if related or parent options have been selected.

For example, record TIMESPEC, presented in Appendix 6-B, contains the note (Req), meaning that this record must reside in the input data set for each simulation. Record CHNGBATH contains the note (Opt), meaning this record is optional and is used only when changes to the bathymetric data are desired. Record XSTRETCH contains the note (C-opt), meaning this record is required only if a stretched Cartesian grid has been specified on the GRIDSPEC record.

57. Input variables, presented in column 2 of each table, are referenced to their respective record fields shown in column 1. Generally, data for each variable occupy a single 8-column data field. However, variables assigned titling or formatting information can occupy several fields.

58. Variable attributes are presented in columns 3 through 6 of each table. Valid data types are listed in column 3 and can be real, integer, or alphanumeric. Abbreviations presented in this column are described below:

Char*16	Alphanumeric character string containing up to 16 characters
Char*8	Alphanumeric character string containing up to 8 characters
Integer	Integer data
Real	Real (floating point) data

59. Column 4 of each table defines whether the respective variable must be assigned a value. Abbreviations listed in this column have identical meanings as those for the records. Default values are listed in column 5. A blank entry in this column denotes that the respective variable is not assigned a default value.

60. Column 6 of each table lists the variables' permitted data type or all valid character strings. Variables having integer or real data types are specified with the following notation:

A	Alphanumeric values
+R	Positive real values
R	Positive, zero, or negative real values
+I	Positive integer values
I	Positive, zero, or negative integer values

61. Variable definitions are listed in table column 7 of each table. Variables whose quantities are unit-dependent contain a reference to that variable designating its system of units. For example, variable TMAX is assigned a value having units defined by variable TUNITS. Variables defining input data units and the record on which they reside are presented below.

Variable	Record	Definition
BUNITS	BATHSPEC	bathymetry/topography data
FUNITS	FUNCTION	tidal and discharge boundary data
GUNITS	GRIDSPEC	numerical grid data
SUNITS	GENSPECS	model computations and output
TUNITS	TIMESPEC	time-dependent variables
WUNITS	WINDSPEC	wind velocity data

62. The types of data processed by CLHYD are extensive and encompass a wide range of possible applications. Since each application is unique, the type of input data required for each study will vary. In this discussion of model input, data have been divided into six categories to present model capabilities and data requirements. These categories are:

- a. Model control specifications.
- b. Grid description.
- c. Physical characteristics.
- d. Boundary conditions.
- e. Wind field specifications.
- f. Output specifications.

63. Table 6-2 presents CLHYD input data records pertaining to each category. A record refers to one line of data, and each record begins with a mnemonic character string to identify one record type from another. Record format and detailed specification for each record are contained in Part IV. While reading Part IV, the user will find it beneficial to refer to Appendix 6-B, where descriptions for each input data record are given.

Model Control Specifications

64. Model control parameters define how the user wants to control the model's execution. Records contained in this category include GENSPECS, TIMESPEC, STARTUP, and ADDTERMS.

65. Record GENSPECS is used to specify the general title of the simulation (TITLE) and the system of units (SUNITS) used for model computations and displaying model results. Variable names are typically given in parentheses. In addition to the general title, other input data records have provisions for titles. Although this information is optional, it can be very helpful when reviewing a series of simulations. A title should specifically state data set attributes, such as data source or collection date, to differentiate it from data used in other simulations.

66. Model output is presented in either English or metric units. However, the user can specify a different system of units for the input data.

Table 6-2

Input Data Set Records

Category	Record Name
Model control specifications	GENSPECS TIMESPEC STARTUP ADDTERMS
Grid description	GRIDSPEC GRIDCORN XSTRETCH YSTRETCH
Physical characteristics	BATHSPEC CHNGBATH FRICTION FRICTABL CHNGFRIC XBARRIER YBARRIER
Boundary conditions	XBOUNDRY YBOUNDRY FUNCTION CNRECORD CONSTIT TERECORD TFRECORD TABELEV TABFLOW
Wind field specifications	WINDSPEC TABWINDS
Output specifications	PRWINDOW RECGAGE RECSNAPS XRECRANG YRECRANG

For example, the user can supply wind velocity data having units of either miles per hour, feet per second, meters per second, or knots. CLHYD will perform the necessary conversion to place the input data into the system of units used for computations.

67. Record TIMESPEC controls the processing of all time-related variables. Variable DT defines the time-step or time interval between consecutive flow field computations and has units of seconds. Variable TUNITS controls the units of <u>all</u> <u>other</u> time-dependent variables. Valid units for TUNITS are hours, minutes, and seconds.

68. For meaningful model results, the selected time-step must be consistent with the Courant criterion, C_r . The maximum permissible time-step size for a given value of C_r can be computed from:

$$C_r = \frac{\sqrt{gH}}{\Delta x/\Delta t} \tag{6-47}$$

where g is the gravitational acceleration, Δx is the dimension of the smallest grid cell within the computational domain, H is the depth at that cell, and Δt is the time-step size. Experience indicates that the value for C_r should be less than 5. Larger values of the Courant number may be permissible at a distance from the area of interest within the computational domain; however, numerical accuracy will be affected.

69. Variable IT1 defines the time-step number at the start of the simulation, and variable IT2 defines the length of the simulation (in time-steps). Typically, a simulation begins at time-step 1 and has a duration ranging from one to several days. This duration provides the hydrodynamic model sufficient time in which to develop accurate tidal circulation fields and avoids the generation of numerical instabilities induced by instantaneously applying forces to a static water basin. Additional details concerning duration are discussed with tidal boundary conditions.

70. Variable NFREQ specifies the frequency at which numerical gage time-history data (i.e., water velocities and free surface elevations) are saved for future processing by the post-processing package in the CMS. Numerical gage locations (locations for which time-histories are saved) are selected with the RECGAGE record, which is discussed in the model output specifications section. Variable ITBRKINC defines the time interval for saving field data for use in a follow-up simulation (see STARTUP record).

71. The STARTUP record defines the flow field conditions at the start of a simulation. Normally, the initial flow field is assumed to be static (i.e., water surface elevations and unit flow rates are set to zero). Although this assumption may not be entirely correct, it is often necessary because prototype data rarely have the resolution to accurately define the flow field throughout the model domain at the start of a simulation. To allow for dampening of transients associated with starting from static initial conditions, the simulation should begin several hours before the time period of interest.

72. Initial conditions can also be supplied from a previous simulation (SELEV = HOTSTART). These simulations must be sequential in time since the second simulation is a continuation of the first. When initial conditions are supplied from a previous simulation, the second simulation is referred to as a "hotstart." Slight computational inaccuracies also exist for hotstart conditions due to data round-off incurred by storing formatted data. These precision errors cause transients that are significantly smaller than those generated from starting with static conditions and can be minimized by overlapping the simulations. Overlapping is performed by saving the hotstart data file approximately 10 to 20 time-steps before the end of the first simulation. The second simulation is then run with this hotstart file. When analyzing model results, the user should ignore the repeated (overlapping) time-steps in the second simulation.

73. When a hotstart is selected, variable IT1 on record TIMESPEC must be set to the time-step when the desired field data were saved. These times are printed in the input data summary file of the preceding run. The hotstart simulation will begin at time IT1 and end at time IT2 + IT1. Therefore, the user should not incorporate the simulation time of the previous run into variable IT2. All remaining time variables should reflect the change in starting time. The STARTUP record also contains variable SECHO. A brief or full report of input data is written to the output file by specifying SECHO equal to SHORT or DETAILED, respectively.

74. Record ADDTERMS must reside in the input data set if either the inertial or dispersion terms are to be computed in the Navier-Stokes calculations. Variable ADVFLAG is set to either NO for no inertial terms or YES to include the inertial terms. Dispersion is set with variable DIFFLAG equal to either NO for no dispersion or YES for dispersion. The value of the

dispersion coefficient is defined by variable AH and is treated as a constant in CLHYD. The value of the Coriolis coefficient is defined by variable COR on record ADDTERMS.

Grid Description

75. The study area is defined in the model via a computational grid. The grid is composed of rectilinear or curvilinear cells, where each cell is assigned a two-dimensional index. The first index (*i*) corresponds to the x-coordinate, and the second index (*j*) corresponds to the y-coordinate. The grid index system is presented in Figure 6-14. All flow field data, such as depths, are assigned and referenced to their respective grid cells with this system. Guidelines for developing grids are discussed in Appendix A of the *CMS User's Manual*.

76. CLHYD permits uniform grids; rectilinear stretched grids, where successive grid cells can smoothly vary in width; or general curvilinear grids. Procedures for constructing a grid are presented in documentation of package CMSGRID (Appendix A of the *CMS User's Manual*). CMSGRID guidelines for grid generation pertaining to hydrodynamic models are therefore useful for CLHYD applications.

77. Selection of grid coordinate systems is controlled by variable GRTYPE on record GRIDSPEC. A uniform, or constant, grid cell size is selected by assigning the character string RECTANG to variable GRTYPE, whereas string RSTRETCH selects a stretched rectilinear grid. If the stretched grid option is selected, record GRIDSPEC must be followed by a set of XSTRETCH and YSTRETCH records (Table 6-3). These records are generated by the interactive grid generation program MAPIT contained in package CMSGRID and can be placed directly into the input data set without modification. The reader can refer to Appendix A of the *CMS User's Manual* for more information on XSTRETCH and YSTRETCH.

78. A general curvilinear grid is selected by assigning the character string CURVILIN to variable GRTYPE. If the curvilinear grid option is selected, record GRIDSPEC must be followed by a GRIDCORN record. This record specifies the format of the x- and y-coordinate (XCT and YCT) data produced by the grid generation program EAGLE; the data directly follow the GRIDCORN record. (The CMSGRID package will contain the EAGLE software.)

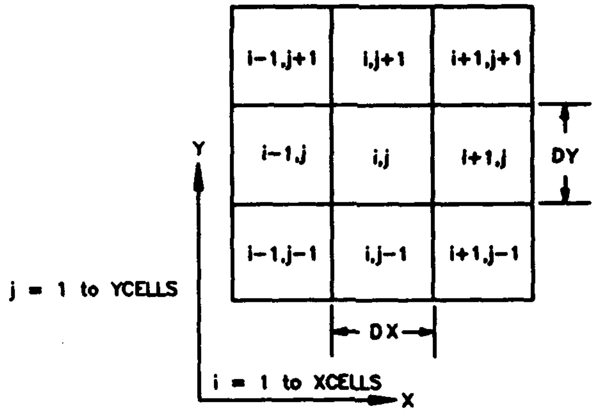

Figure 6-14. Definition of coordinate system
and grid cell convention

79. Variable GUNITS on record GRIDSPEC controls the system of units for the computational grid. Valid units are feet and meters. CLHYD will convert the data to the system of units for computations (SUNITS) internally. Variables ICELLS and JCELLS specify the number of grid cells in the x- and y-directions, respectively. Variables ALXREF and ALYREF on record GRIDSPEC specify a grid's overall length in the x- and y-directions, respectively.

Table 6-3

Sample XSTRETCH and YSTRETCH Records

XSTRETCH	1	4	-.696333695	.696333695	.933460501
XSTRETCH	4	9	-6.69031772	5.80606023	.277821490
XSTRETCH	9	19	.143110486	.710267924	.770050578
XSTRETCH	19	26	.167892340	.730987967	.809764231
YSTRETCH	1	17	-.500000000	.500000000	1.00000000
YSTRETCH	17	26	.177832310	.755987967	.823454231

The variable XMAP is assigned the value of the map scale if relative map distances were used in generating the grid. For example, a map with a scale of 1:80,000 is used to generate a stretched rectangular grid. If the physical map distances (i.e., distances computed using the appropriate scaling) are

used to generate the mapping coefficients, then XMAP is 1.0 because no conversion is necessary. However, if the map distances (i.e., grid distances measured in map inches) are used to generate the mapping coefficients, then XMAP must be 6666.67 to convert map inches to physical distances (e.g., in feet).

Physical Characteristics

80. A study area's physical characteristics include its (a) topography/bathymetry, (b) bottom friction coefficients, and (c) if applicable, any barriers or obstructions influencing tidal circulation or storm surge levels. Records pertaining to each of the above topics are described individually in the following sections.

Topography/bathymetry

81. Each grid cell must be assigned a water depth or land elevation. Topography/bathymetry data are referenced to an arbitrary datum. Typically, the map datum from which the depths are taken is used. Water cells are designated by positive values, whereas land cells are zero or negative values.

82. One BATHSPEC record is required for defining the general characteristics of the topography/bathymetry array and must precede this array. Variable BUNITS defines the units of topography/bathymetry data. Valid units are feet, meters, or fathoms. The input sequence for reading this array is controlled by variable BSEQ. Eight options for the input sequence are available for reading the array data and are documented in Table 6-4. As an example, for the first input sequence (Figure 6-15), the depths are read along the x-direction, then y is incremented to a value of 2, and again the sweep in the x-direction takes place. This procedure is repeated until the entire array is read. The input format for reading this array can be selected by the user with variable BFORM.

83. The maximum water depth is specified with variable DLIMIT, and any array values deeper than DLIMIT are set to DLIMIT (in BUNITS). Grid-wide adjustments to land elevations contained in the topography/bathymetry array can be made with variable LDATUM. The value assigned to this variable is subtracted from all land cells in the grid. Positive LDATUM values will increase land elevations, whereas negative values will decrease land elevations. Similarly, grid-wide adjustments to water depths can be made with

Table 6-4

Input Sequence for Array Data

No	Sequence	Description
1	XY	DO 1 J=1,JCELLS 1 READ(LUN,BFORM) (VAR(I,J),I=1,ICELLS)
2	-XY	DO 2 J=1,JCELLS 2 READ(LUN,BFORM) (VAR(I,J),I=ICELLS,1,-1)
3	X-Y	DO 3 J=JCELLS,1,-1 3 READ(LUN,BFORM) (VAR(I,J),I=1,ICELLS)
4	-X-Y	DO 4 J=JCELLS,1,-1 4 READ(LUN,BFORM) (VAR(I,J),I=ICELLS,1,-1)
5	YX	DO 5 I=1,ICELLS 5 READ(LUN,BFORM) (VAR(I,J),J=1,JCELLS)
6	-YX	DO 6 I=1,ICELLS 6 READ(LUN,BFORM) (VAR(I,J),J=JCELLS,1,-1)
7	Y-X	DO 7 I=ICELLS,1,-1 7 READ(LUN,BFORM) (VAR(I,J),J=1,JCELLS)
8	-Y-X	DO 8 I=ICELLS,1,-1 8 READ(LUN,BFORM) (VAR(I,J),J=JCELLS,1,-1)

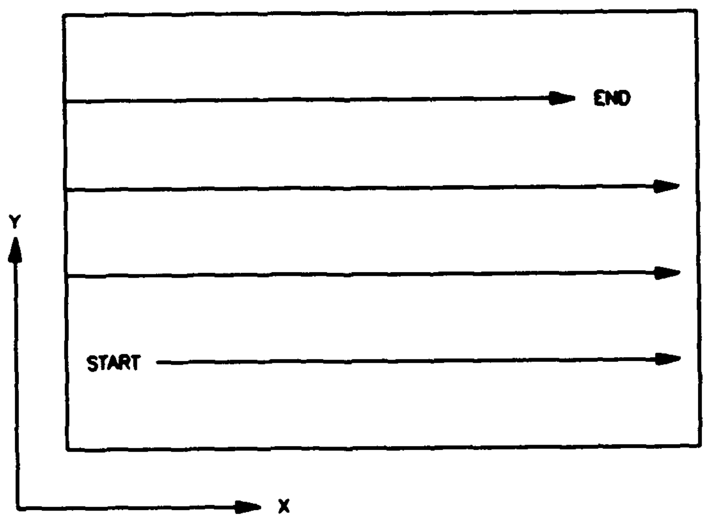

Figure 6-15. Input sequence - option 1

variable WDATUM. The value assigned to this variable is added to all water cells. Since these cells have positive values, positive WDATUM values produce deeper basins, and negative WDATUM values produce shallower basins.

84. Changes to the topography/bathymetry array can also be made to individual cells, or a group of cells with record CHNGBATH. This record allows the user to quickly change values assigned to the bathymetry array (using variable BATH) without editing the array itself. It should be noted that (a) values of the variable BATH on the CHNGBATH record are assumed to have units consistent with those selected for bathymetry/topography (i.e., variable BUNITS on record BATHSPEC), and (b) LDATUM and WDATUM are not applied to cells specified with record CHNGBATH; therefore, the effect of nonzero LDATUM and WDATUM must be included in the value of variable BATH.

85. Variables X1INDX and X2INDX on the CHNGBATH record specify the minimum and maximum cell numbers in the x-direction, respectively, where the bathymetry/topography value will change. Similarly, variables Y1INDX and Y2INDX on the CHNGBATH record specify the minimum and maximum cell numbers in the y-direction, respectively, where the bathymetry/topography value will change. More than one CHNGBATH record is permitted.

Bottom friction coefficient

86. Several choices are available for specifying bottom friction coefficients. Bottom friction coefficients may be specified as constant Manning's *n* values (FRDEF = CONSTANT), as individual values for each cell (FRDEF=TABULAR), or as functions of depth/elevation (FRDEF = VARYBATH). For the constant value option, separate friction coefficients can be assigned to land and water cells. Friction coefficients for land are assigned to variable FRLAND, and coefficients for water cells are specified by variable FRWATR. A coefficient is assigned to each cell based on its topography/bathymetry value at the start of a simulation and will remain constant throughout the simulation.

87. The tabular friction option (FRDEF=TABULAR) requires friction coefficients for each individual cell. The friction array must follow immediately after the FRICTION record. The input sequence for reading the friction array is controlled by variable FSEQ on record FRICTION. Eight options for the input sequence are available for reading the array data and are documented in Table 6-4. The input format for reading the friction array can be selected by the user with variable FFORM on record FRICTION.

88. The depth-variable friction option requires a least two FRICTABL records, which must follow immediately after the FRICTION record in the input data set. Each FRICTABL record must contain a depth/elevation (FDEPTH) and a corresponding friction value (FRICT) for creating a tabular friction function. Cells with a water depth greater than or equal to FDEPTH are assigned a friction value of FRICT. Cells whose depths are deeper than the deepest depth entered in the table are assigned the friction coefficient corresponding to the deepest table depth.

89. In deep water, bottom friction has a negligible effect on long-wave hydrodynamics. Variable FDMAX on record FRICTION defines the maximum depth where bottom friction influences the hydrodynamics. It is provided for reducing computer memory requirements when the depth-variable option is requested and has a default value of 300.0 ft.

90. Friction coefficients can also be assigned to individual cells, or group of cells with record CHNGFRIC. Record CHNGFRIC overrides the above options for all cells entered on this record. This feature permits the user to change a cell's friction coefficient in certain areas, such as rivers, where parameters differ from the norm. Variables (X1INDX, Y1INDX) and (X2INDX, Y2INDX) define the "patch" of cells where friction values are to be changed. More than one CHNGFRIC can be used in a simulation. These records must follow FRICTION and, if applicable, FRICTABL records.

Barriers

91. Subgrid barriers refer to flow field obstructions, such as breakwaters, whose widths are much narrower than the widths of adjacent grid cells, but have lengths that are equal to or greater than those of a grid cell. Barriers are treated as exposed, impermeable structures in model CLHYD.

92. Barriers that prevent or impede flow in the x-direction (i.e., perpendicular to the x-axis) are specified with XBARRIER records (Figure 6-16). A barrier for a particular cell is defined at the cell face, where the velocity is also defined. Barrier grid locations are defined with variables BRPOS1, BRPOS2, and BRPOS3. Variable BRPOS1 is assigned the barrier's grid cell X-index, and variables BRPOS2 and BRPOS3 are assigned the barrier's starting and ending grid cell Y-indices, respectively.

93. Similarly, YBARRIER records define those barriers that prevent or impede flows in the *y*-direction. Variable BRPOS1 is assigned the barrier's

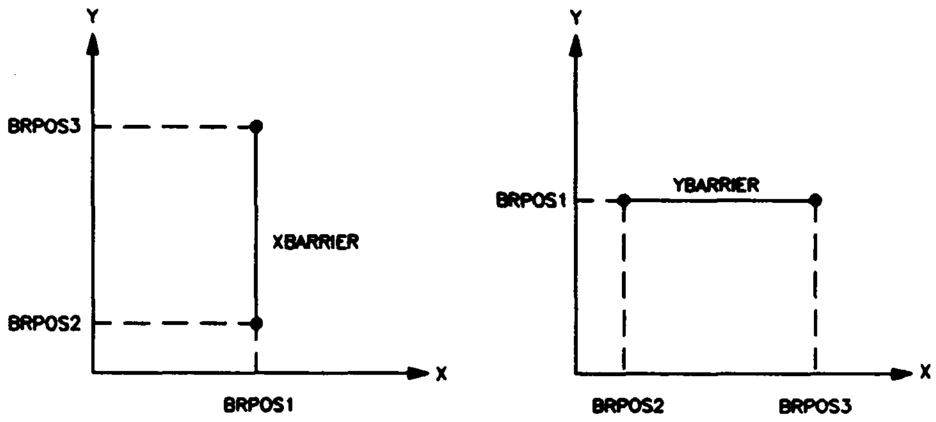

Figure 6-16. Definition of XBARRIER mad YBARRIER

grid cell *Y*-index. Variables BRPOS2 and BRPOS3 are assigned the barrier's starting and ending grid cell *X*-indices.

Boundary Conditions

94. CLHYD is generally applied in regions where at least one grid boundary lies in open water. For example, in open coast regions, the seaward boundary may be located along the Continental Shelf. In these cases, the flow field is typically driven or forced by prescribing a time-series of water surface levels along this boundary throughout a simulation. Regions may also contain a river whose flow influences local circulation patterns. These river flow rates can be specified as a function of time.

95. To encompass as many modeling scenarios as possible, three types of open boundary conditions are incorporated into this model including:

a. Tidal elevation.

b. Discharge.

c. Uniform flux condition

Discussion of these open boundary conditions is presented in three parts. First, an overview of each type of open boundary describes its application and attributes. Second, input data requirements for defining a boundary's grid

location are presented. Third, input data requirements for entering time-series data are described.

Overview of open boundary conditions

96. With the tidal elevation boundary condition, the flow field is driven by specifying the water surface elevations as a function of space and time along a grid's outer boundary. Water surface elevations are measured relative to the topography/bathymetry datum and can be supplied from tidal constituent parameters or tabulated data.

97. Two options are available for specifying the spatial distribution of data along a boundary. The first option applies a spatially constant elevation function across a boundary segment where each cell in the segment acts in unison, having identical water surface elevations at each time-step. This option is normally applied along a grid's lateral boundary (i.e., perpendicular to the shoreline) in areas of deep water. It can also be used along a seaward boundary if no significant phase or elevation differences occur along this segment.

98. The second option is a spatially variable elevation forcing boundary where separate time-series functions are specified at each end of a boundary segment. Elevations for each cell within the boundary segment are obtained by linearly interpolating the two forcing functions (at each time-step). This option is typically applied along the grid's seaward boundary. A boundary can be treated as one continuous segment, or as several segments.

99. Discharge boundary conditions can be specified at any interior grid cell face. An error message will be printed and execution terminated if this boundary condition is specified at the edge of the computational grid. Furthermore, depths on each side of the boundary cell faces must be greater than zero, signifying water cells. Discharges are required to have units of flow per unit width (i.e., cubic feet/second/foot or cubic meters/second/meter), and flow trajectories are referenced relative to the grid axes. Positive discharge rates define flows directed in the positive x- or y-directions, whereas negative discharge rates define flows directed in the negative x- or y-direction.

100. A uniform flux boundary condition is similar to a river discharge boundary condition in that a flux is applied at the boundary cell face. However, the flux through the cell face is computed internally by the model, as opposed to a user-defined flux. This boundary condition assumes that the

flux through the boundary cell face equals the flux through the opposing cell face.

101. Since the uniform flux boundary condition does not drive a flow field, its application is limited. However, there are two situations where it can be applied. First, it can be applied across the lateral boundaries near the shoreline (Figure 6-17). Tidal signals generated from constituents, which are normally prescribed as a forcing function along the seaward boundary, should not be used in this reach because bottom friction effects attenuate the tidal signal. Hence, forcing a tidal signal in this reach may not accurately depict the physical processes occurring within the study area.

102. Second, the uniform flux boundary condition may be applicable to steady-state, storm surge analyses of lakes. However, wind must be the only driving force causing surge, and resulting seiches cannot be simulated with this boundary condition.

103. Because the uniform flux boundary condition provides an estimate of the actual flow entering/exiting the grid, its use will introduce error into the flow field solution. Bottom friction effects can dampen these inaccuracies, ensuring accuracy of results in the area of interest, if the uniform flux boundaries are placed a suitable distance away from the area of interest. Generally, this distance ranges from 1.5 to 2.0 times that distance

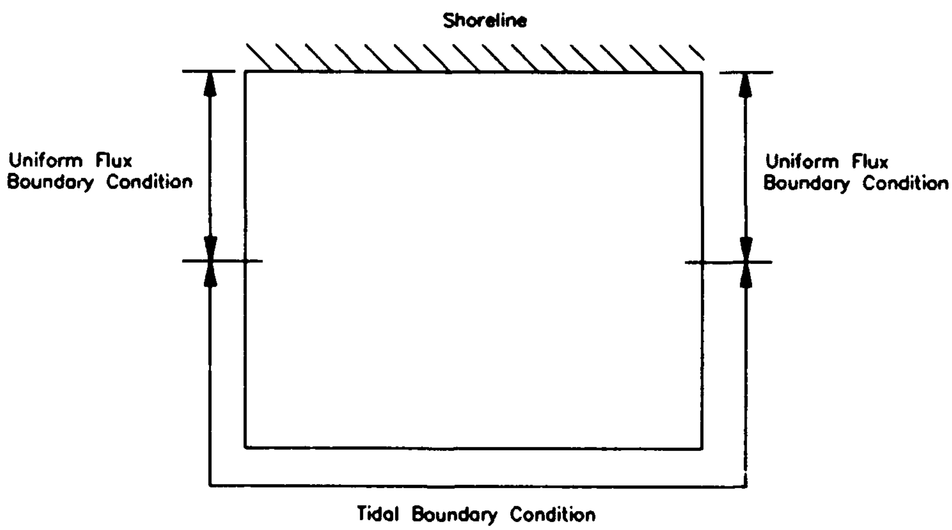

Figure 6-17. Uniform flux boundary condition

measured from the shoreline to the seaward boundary (if it is located at the Continental Shelf).

Spatial description of open boundaries

104. Each distinct open boundary must be declared by either an XBOUNDRY or a YBOUNDRY record. Record XBOUNDRY defines a boundary that induces or forces flow in the x-direction (i.e., boundary is perpendicular to the x-axis) (Figure 6-18). Conversely, a YBOUNDRY record defines a boundary that is perpendicular to the y-axis.

105. Boundary types are declared on records XBOUNDRY and YBOUNDRY with variable BNDTYP and can be assigned any of the three options previously discussed: (a) spatially constant tide boundaries are selected with character string CONSTELV, (b) spatially variable tide boundaries are chosen with string INTRPELV, (c) spatially constant discharge boundaries are selected with string CONSTDIS, and (d) uniform flux boundaries are selected with string UNIFLUX.

106. This model employs a staggered grid cell system where water surface levels, x-direction velocities, and y-direction velocities are defined at different locations on a cell. These positions were defined in Figure 6-4. Elevation are referenced relative to a cell's center, and river discharge boundaries are specified along cell faces.

107. Boundary grid positions are defined with variables BNPOS1, BNPOS2, and BNPOS3. For XBOUNDRY records, variable BNPOS1 is assigned the boundary's *X*-index, whereas variables BNPOS2 and BNPOS3 are assigned the *Y*-indices of the starting and ending cells, respectively (Figure 6-18). For YBOUNDRY records,

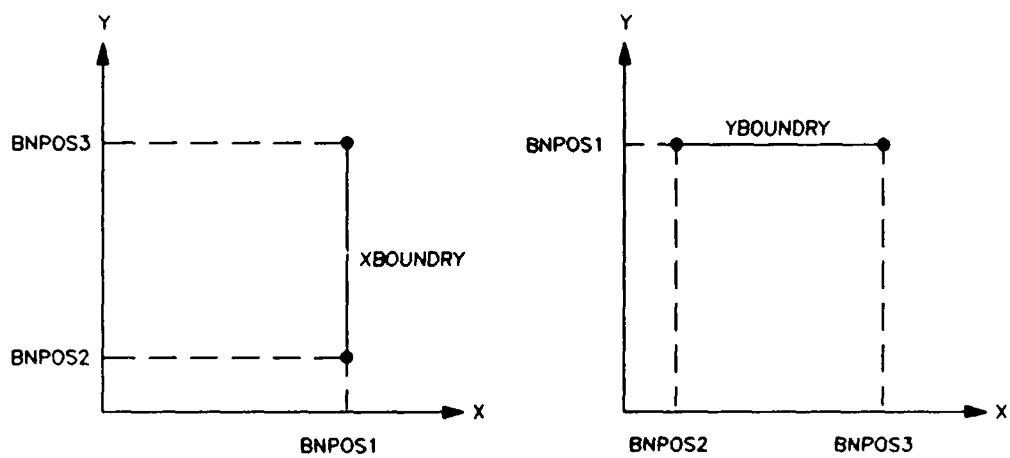

Figure 6-18. Definition of XBOUNDRY and YBOUNDRY

variable BRPOS1 is assigned the boundary's *Y*-index, and variables BRPOS2 and BRPOS3 are assigned the *X*-indices of the starting and ending cells, respectively. Boundaries can be identified by assigning each one a boundary name with variable BNDNAM on the XBOUNDRY or YBOUNDRY records.

Time-series description of open boundaries

108. Time-series data are required for driving the flow field for all of the boundary options: (a) spatially constant elevation, (b) spatially variable elevation, and (c) spatially constant discharge boundary options. XBOUNDRY and YBOUNDRY variable BNDFN1 (for all three options) and BNDFN2 (for spatially variable elevation boundaries only) define which group of time-series data is to be used to drive the boundary, and correspond to the function index number assigned to variable FUNNO on record FUNCTION. For example, an application may have a spatially variable elevation boundary and two spatially constant elevation boundaries (Figure 6-19). This application would require two FUNCTION records (one at each end of the spatially variable boundary) to define the time series at two locations. These values are also used along the spatially constant boundaries.

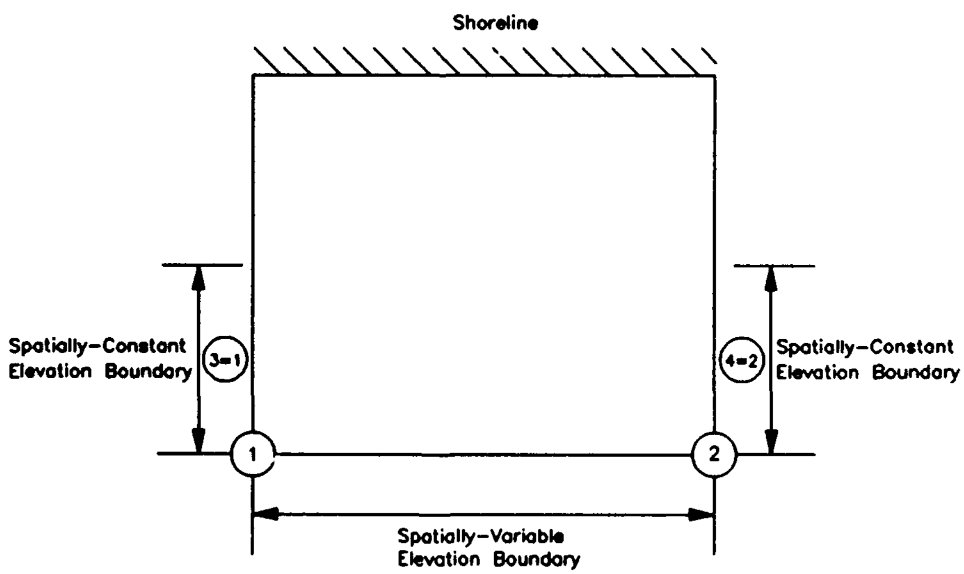

Figure 6-19. Example showing use of BNDFN1, BNDFN2,and FUNNO variables

109. The FUNCTION record is required for time-series data and defines the character of the forcing function driving the boundary. Variable FUNTYP on record FUNCTION is used to determine if the boundary is forced with harmonic constituents (HARMCNST), tabular elevation data (TABELEVS), or tabular discharge data (TABFLOWS). Variable FUNITS defines the units used for the given elevations or flows. The forcing function can be adjusted by shifting it in time (phase shift) or in the vertical (datum shift), or by multiplying the entire time-series by an adjustment factor. Variables FSHIFT, FDATUM, and FMULT on record FUNCTION, respectively, are used to perform these tasks. The forcing function can be gradually spline-fit from initial conditions (usually zero) to the given function value over the time period assigned to variable FEATHR defined on record FUNCTION.

Harmonic constituents

110. A boundary driven with harmonic constituents (FUNTYP = HARMCNST) requires at least two records to follow the FUNCTION record: one CNRECORD record and at least one CONSTIT record. First, the CNRECORD record specifies the physical coordinates and timing associated with a constituent forcing function. The calendar date (variables RYEAR, RMONTH, and RDAY), time at the start of the simulation (variable RHOUR), and the west longitude of the grid cell where the forcing function is applied (RLONG) are specified on record CNRECORD. Dates and times can be referenced to Greenwich Mean Time (GMT) or local time. GMT is assumed if the longitude (RLONG) equals zero, and nonzero longitude values signal a local time specification. CNRECORD also contains variable RNAME for specifying a record name for the forcing function.

111. One CONSTIT record is needed for each constituent used in generating the time-series data. Variable CNAME on record CONSTIT defines which constituents are selected. Table 6-5 provides a list of the 37 constituents available. A maximum of 37 constituents can be selected (requiring 37 CONSTIT records) and are referenced with the naming convention developed by the National Ocean Survey (NOS). Variable CNAME on record CONSTIT is used to select any of the constituents listed in Table 6-5. Other data entered on this record include the constituent's amplitude (CAMP) and epoch (CEPOCH).

Tabular elevation time series

112. Tabular elevation data can be used to specify, or force, a boundary. CLHYD can access components of program TIDEGEN in package CMSUTIL (Appendix B of the *CMS User's Manual*) to internally compute the tabular

Table 6-5

List of Available Constituents

NOS Name	Description
M2	Semidiurnal
S2	Semidiurnal
N2	Semidiurnal
K1	Diurnal
M4	Shallow-water quarter diurnal
O1	Diurnal
M6	Shallow-water sixth diurnal
MK3	Shallow-water terdiurnal
S4	Shallow-water quarter diurnal
MN4	Shallow-water quarter diurnal
NU2	Semidiurnal
S6	Shallow-water sixth diurnal
MU2	Semidiurnal
2N2	Semidiurnal
OO1	Diurnal
LAMBDA2	Semidiurnal
S1	Diurnal
M1	Diurnal
J1	Diurnal
MM	Long-period
SSA	Long-period
SA	Long-period
MSF	Long-period
MS	Long-period
RHO1	Diurnal
Q1	Diurnal
T2	Semidiurnal
R2	Semidiurnal
2Q1	Diurnal
P1	Diurnal
2SM2	Shallow-water semidiurnal
M3	Terdiurnal
L2	Semidiurnal
2MK3	Shallow-water terdiurnal
K2	Semidiurnal
M8	Shallow-water eighth diurnal
MS4	Shallow-water quarter diurnal

elevation time-history data from tidal constituents. Each tabular tide boundary requires a TERECORD to precede the actual water surface elevation data. The elevation data can be given at even (constant) time increments (RRINT = Real number) or at user-specified (irregular) times (RRINT = IRREGINT).

113. Constant time-interval data are entered as a one-dimensional array immediately following record TERECORD. The time interval between entries is specified with variable RRINT (in TUNITS) on record TERECORD. The total number of tabular elevation data entries in the one-dimensional array is specified with variable RENT. The user must also specify which of the array elements corresponds to the start of the simulation with variable RSTART. Typically, this element is the first value in the array. However, this variable must be updated for hotstart simulations. Variable RFORM is used to specify the format for reading the one-dimensional array, and variable RNAME is used for naming the tabular tide record.

114. For irregularly spaced (in time) tabular tide data, one TERECORD and a series of TABELEV records are required. Variable RRINT on record TERECORD is set to IRREGINT for irregularly spaced (in time) tide data. The remaining variables on this record are ignored with this option.

115. One TABELEV record is needed for each tabular tide entry. The elevation (FMAG in FUNITS) and time of occurrence (FHR, FMIN, FSEC in hours, minutes, and seconds) are required on each TABELEV record. Elevations are linearly interpolated at those time-steps occurring between entries; therefore, at least two TABELEV records are required. The first TABELEV record must specify the elevation at or before the start of the simulation, whereas the last TABELEV record must specify the elevation at or after the end of the simulation.

Tabular river discharge time series

116. River discharge boundary conditions can be specified at any interior grid cell face. An error message will be printed and execution terminated if this boundary condition is specified at an outer-boundary face. Furthermore, depths on opposite sides of the river boundary cell face must be greater than zero, signifying a water cell. Discharges are required to have units of flow per unit width (i.e. cubic feet/second/foot or cubic meters/second/meter).

117. Each river discharge boundary function requires one TFRECORD (analogous to the tabular tide function record (TERECORD) discussed previously) to precede the flow data. The flow data can be given at even (constant) time increments (RRINT = real number), or at user-specified (irregular) times (RRINT = IRREGINT).

118. Constant time-interval data are entered as a one-dimensional array immediately following record TFRECORD. The time interval between entries is specified with variable RRINT (in TUNITS) on record TFRECORD. The total number of tabular flow data entries in the one-dimensional array is specified with variable RENT. The user must also specify which of the array elements corresponds to the start of the simulation with variable RSTART. Typically this element is the first value in the array. However, this variable must be updated for hotstart simulations. Variable RFORM is used to specify the format for reading the one-dimensional array, and variable RNAME is used for naming the tabular flow record.

119. For irregularly spaced (in time) tabular flow data, one TFRECORD and a series of TABFLOW records are required. Variable RRINT on record TFRECORD is set to IRREGINT for irregularly spaced (in time) flow data. The remaining variables on this record are ignored with this option.

120. One TABFLOW record is needed for each tabular flow entry. The flow rate (FMAG in FUNITS) and time of occurrence (FHR, FMIN, FSEC in hours, minutes, and seconds) are required on each TABFLOW record. Flow rates are linearly interpolated at those time-steps occurring between entries; therefore, at least two TABFLOW records are required. The first TABFLOW record must specify the flow rate at or before the start of the simulation, whereas the last TABFLOW record must specify the flow rate at or after the end of the simulation.

Uniform flux boundary condition

121. The uniform flux boundary condition (UFBC) is similar to a river discharge boundary condition in that a flux is applied at the boundary cell face. However, the flux through the cell face is computed internally by the computer as opposed to specifying the flux for a river boundary. This boundary condition assumes that the flux through the boundary cell face is equal to the flux through the opposing cell face.

122. Since the UFBC does not drive a flow field, its application is limited. Therefore, care must be taken in applying it. Selecting an inappropriate reach (length) of the boundary may lead to erroneous results. The user should test the sensitivity of choice by trying other segment lengths that band the chosen reach.

Wind-Field Specifications

123. CLHYD can simulate hydrodynamics influenced by uniform, nonuniform, steady, and time-varying wind fields. However, wind-field calculations are only performed if record WINDSPEC and related records reside in the input data set. Uniform (spatially and temporally constant) wind fields are specified by assigning character string UNIFSTRS or UNIFSPED to variable WNTRVL on record WINDSPEC. The WINDSPEC record is followed by one TABWINDS record specifying the x- and y-components of the constant wind stress or speed (Table 6-6).

124. Nonuniform (spatially variable) wind fields are specified by assigning character string SPVRSTRS or SPVRSPED to variable WNTRVL on record WINDSPEC. The WINDSPEC record is followed by one TABWINDS record specifying the sequence (TSEQ) and format (TWFORM) of the wind-stress or wind-speed arrays, similar to the bathymetry sequence (BSEQ) and format (BFORM) (see Figure 6-15). The TABWINDS record is then followed by the wind-stress or wind-speed arrays.

125. Time-variable, spatially constant wind fields are specified by assigning character string TVRUNISP or TVRUNIST to variable WNTRVL on record WINDSPEC. The WINDSPEC record must be followed by at least two TABWINDS records that specify the x- and y-components of the wind stress or speed at specific times during the simulation.

126. Wind fields that vary in time and space are specified by assigning character string TSPVRSTR or TSPVRSPD to variable WNTRVL on record WINDSPEC. The WINDSPEC record is followed by at least two TABWINDS records, and each TABWINDS record is followed by wind-stress or wind-speed arrays.

127. For the time-variable uniform wind options, one TABWINDS record is typically entered for each hour of the simulation. (More frequent data occasionally exist.) The model will then linearly interpolate to obtain wind-speed and direction values at the time interval specified by WINTRP on record WINDSPEC. It should be noted that WINTRP must be assigned a value that is an integer multiple of the time-step DT.

128. Variable WUNITS declares the system of units for wind magnitudes. Valid units are: (a) miles/hour, selected with character string MPH; (b) feet/second, chosen with FPS; (c) meters/second, specified with MPS; and (d) knots, selected with KNOTS.

Table 6-6

<u>Options for Wind-Field Specifications</u>

<u>Cases 1 and 2</u> Constant wind field with respect to time and space

WINDSPEC	UNIFSTRS	MPH	WINTRP		WIND DATA NAME
or	UNIFSPED				
TABWINDS			TAUX	TAUY	

<u>Cases 3 and 4</u> Spatially variable wind field

WINDSPEC	SPVRSTRS	MPH	WINTRP		WIND DATA NAME	
or	SPVRSPED					
TABWINDS					TSEQ	TWFORM

(Array of TX1)
(Array of TY1)

<u>Cases 5 and 6</u> Time-variable wind field

WINDSPEC	TVRUNISP	MPH	WINTRP		WIND DATA NAME
or	TVRUNIST				
TABWINDS	IDAY(1)	IHOUR(1)	TAUX(1)	TAUY(1)	
TABWINDS	IDAY(2)	IHOUR(2)	TAUX(2)	TAUY(2)	
TABWINDS	IDAY(3)	IHOUR(3)	TAUX(3)	TAUY(3)	

<u>Cases 7 and 8</u> Time and spatially variable wind field

WINDSPEC	TSPVRSTR	MPH	WINTRP		WIND DATA NAME	
or	TSPVRSPD					
TABWINDS	IDAY(1)	IHOUR(1)			TSEQ	TWFORM
(Array of TX1)						
(Array of TY1)						
TABWINDS	IDAY(2)	IHOUR(2)				
(Array of TX1)						
(Array of TY1)						

129. Strong winds instantaneously applied to a static water basin, such as at the start of a simulation, will generate extraneous water oscillations that can lead to the model becoming unstable or can remain in the model solution for a significant portion of a simulation. These problems can be alleviated by gradually increasing wind magnitudes from zero at the start of

the simulation, to the actual magnitude several hours into the simulation. This task can be accomplished by adjusting wind magnitudes entered on the TABWINDS records.

130. All TABWINDS records must immediately follow the WINDSPEC record, Furthermore, times entered on these records must correspond to the simulation's starting time defined by variable IT1 on record TIMESPEC. The first TABWINDS record must occur no later than the start of the simulation. For the time-variable option, the last TABWINDS record must occur no earlier than the end of the simulation.

131. For example, if the simulation begins at 0 hr 0 min and has a duration of 36 hr, the first TABWINDS record must specify wind conditions occurring at (or before) 0 hr 0 min, and the last record must occur at 36 hr 0 min (or later). Should the simulation be continued with the hotstart option, all times entered on the TABWINDS record are referenced to the original starting time. Assuming the hotstart begins at hour 36 and has a duration of 24 hr, the first TABWINDS record must have as its time no later than 36 hr 0 min. The last TABWINDS record must have as its time 60 hr 0 min, (or later).

Output Specification

132. CLHYD provides several options for displaying output, including: (a) numerical gage time-histories at selected grid cells (e.g., elevations, wind, and/or water velocities), (b) wind or water velocity vector fields at user-specified times during a simulation, and (c) an output listing containing an input data summary and a printout of field arrays (e.g., free surface elevations, water velocities, wind velocities, bathymetry). CMSMODEL will prompt the user to provide a name for each specific output file (i.e, hydrograph file name for RECGAGE data, snapshot file name for field array (REC-SNAPS) data). These data files can be used as input to hydrodynamic models as well as wave hindcast models. Data can be displayed in either tabular or graphical form with the post-processing package CMSPOST discussed in Appendix C of the *CMS User's Manual*.

133. The output listing containing a summary of the input data set is generated for every simulation. Error and warning diagnostic messages are

also contained in this listing. A sample output listing containing a summary of the input data set is presented in Figure 6-20.

134. Each input record is summarized in tabular form with a heading containing its record identification label followed by a brief description of that record's function. A table is composed of each variable's name, a description of that variable (including its units, when applicable), and an error diagnostic note.

135. CLHYD contains error diagnostic features that inspect an input data set for possible errors. These features include: (a) comparing an inputted value against a range of quantities that are representative for that variable, (b) checking for misspelled character data, and (c) checking for missing data. The error diagnostic note can be assigned one of three character strings, which are: (a) "FATAL" for errors where the model cannot execute given the value supplied, (b) "WARN" for data that are outside the range of values typically selected for that variable, and (c) a null string for instances where an error condition has not been identified. Although this model contains error diagnostic capabilities, the user should thoroughly inspect the input data summary to ensure that the data are correct.

136. Field arrays (e.g., free surface elevations, water velocities, wind velocities, bathymetry) are printed along with the input data summary by including one or more PRWINDOW records. Variable WPRVAR on record PRWINDOW is used to specify which field arrays are to be printed (e.g. WPRVAR = E for water surface elevations). The user can control printing of field arrays through the course of a simulation by specifying the starting (WPRSTR) and ending (WPREND) time-steps, together with the time interval (WPRINT), at which the data will be printed. Furthermore, the user can specify printing of subgrid regions (or windows) as opposed to the entire grid, if he so chooses. This is done by specifying the x- and y-boundaries of a subgrid region with variables WXCEL1, WXCEL2, WYCEL1, and WYCEL2.

137. Gage time-histories of field arrays are saved with record RECGAGE. One RECGAGE record is required for each desired output location where the field array data are to be saved. A maximum of 120 gages, each containing up to 1,000 points, can be processed. All gage time-histories are stored in one file and are processed by programs HYDADD, HYDLST, and HYDPLT in package CMSPOST.

COASTAL MODELING SYSTEM (CMS): CLHYD . VERSION 1.0

— CLHYD SIMULATION NO. 2: TIDE WITH NONLINEAR TERMS —

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*				

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		*	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	75		*	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	30	
ALXREF	TOTAL LENGTH IN X DIRECTION	37500.00		*	ALYREF	TOTAL LENGTH IN Y DIRECTION	30000.00	

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	30.0		*	TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	SECONDS	
IT1	TIMESTEP AT START OF MODEL SIMULATIO	1		*	IT2	TOTAL NUMBER OF TIMESTEPS SIMULATED	2520	
NFREQ	TIMESTEP INTERVAL TO SAVE GAGE DATA	12		*	DTHOTS	TIMESTEP INTERVAL TO SAVE HOTSTARTS	0	

***** ADDTERMS CARD: SPECIFICATION OF ADDITIONAL TERMS IN GOVERNING EQUATIONS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
ADVFLAG	GOVERNS USE OF ADVECTION TERMS	YES		*	DIFFLAG	GOVERNS USE OF DIFFUSION TERMS	YES	
DIFCOF	DIFFUSION COEFFICIENT	5.0000		*	CORIOLIS	CORIOLIS COEFFICIENT	0.0000	

***** STARTUP CARD: SPECIFICATION OF INITIAL CONDITIONS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SELEV	INITIAL WATER SURFACE ELEVATION	4.05		*	SECHO	AMOUNT OF INPUT DATA TO BE PRINTED	SHORT	
IHOURO	HOUR AT START OF SIMULATION	0		*	IMINO	MINUTE AT START OF SIMULATION	0	
ISECO	SECOND AT START OF SIMULATION	0		*	SNAME	NAME OF STARTUP CONDITIONS		

***** HYDROGRAPH AND VELOCITY MEASUREMENTS: 2 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	19	16				INLET GAGE
2	42	15				OCEAN GAGE

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA * STARTING ENDING STARTING ENDING * TIMES TO PRINT (SECONDS): * VARIABLE FIELD

Figure 6-20. Sample output listing

138. Variables IST and JST on record RECGAGE define the grid location where field arrays are saved. The time interval at which these data are stored is controlled by variable NFREQ on record TIMESPEC.

139. Record RECSNAPS allows the user to store wind and water velocity data for generating vector plots. The stored data can also be used as input to other models. Data can be saved at regular time intervals (SNPTYP = INTERVAL), at specific time-steps during a simulation (SNPTYP = TIMES), or both. For data storage at regular time intervals, SNPSTR defines the time-step at which data storage is to begin, SNPEND defines the time-step at which data storage is to end, and SNPINT is the regular time-step interval at which data storage occurs. For data storage at user-specified times, one RECSNAPS record is required for each time (SNPTIM) at which a snapshot is to be recorded. More than one RECSNAPS record can be used, and up to 100 snapshots can be saved in a file. These data can be processed with programs SNAPCON, SNAPLST, and SNAPVEC, which reside in package CMSPOST.

140. Records XRECRANG and YRECRANG allow the user to save data describing discharges across arbitrary transects. These data allow the user to check flow through various tributaries or to determine the tidal prism. One record is required for each desired transect. A maximum of 120 ranges, each containing up to 1,000 points, can be processed. All range time-histories are stored in one file and are processed by programs HYDADD, HYDLST, and HYDPLT in package CMSPOST.

141. Similar to barriers and boundaries, variable RPOS1 defines the x-cell position (for XRECRANG) or the y-cell position where data are to be recorded. Variables RPOS2 and RPOS3 define the range, or extent, of the recording range location. For XRECRANG, records RPOS2 and RPOS3 indicate the y-extent, and for YRECRANG, records RPOS2 and RPOS3 indicate the x-extent. The time interval at which these data are stored is controlled by variable NFREQ on record TIMESPEC. RNAME is used to name the range data.

142. Three sets of illustrative examples are included in this section to demonstrate CLHYD's capabilities. The grid geometry for the first set of examples is the same; however, the forcing functions vary. This set of examples was also presented with model WIFM, which is another long-wave hydrodynamic model in CMS. The second set of examples involves a series of tests using orthogonal curvilinear grids. The last example involves the application of CLHYD at Indian River Inlet, Delaware.

143. The 75- by 30-cell study area used in the first set of examples consists of an open ocean and back-bay area joined through an inlet, and two barrier islands (Figures 6-21 and 6-22). The inlet is protected with two jetties. A small island situated in the back bay is also simulated. The first set of examples includes: (a) a tidal forcing simulation without advection and dispersion terms or feathering, (b) a tidal forcing simulation starting at slack water and with nonlinear terms, (c) simulation (a) with the inclusion of a steady wind field, and d) simulation (a) with the inclusion of river inflow into the back-bay area. Although the examples show individual applications of wind and discharge forcing functions, they can be combined and applied simultaneously.

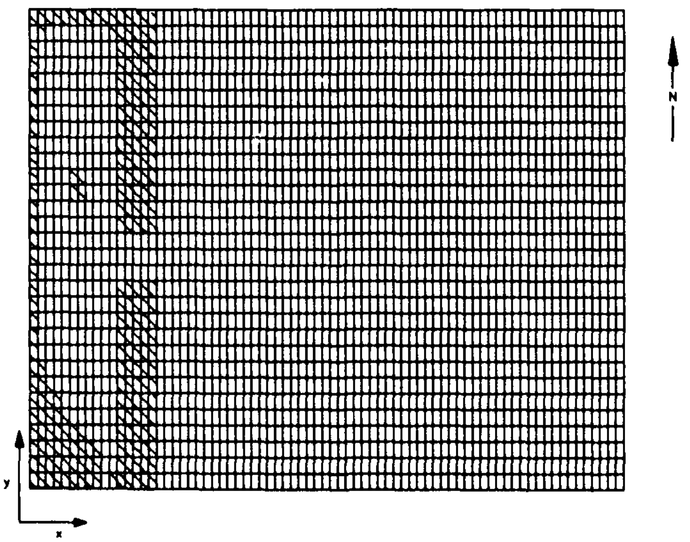

Figure 6-21. Computational grid for four examples

Tidal Forcing Simulation

144. The tidal forcing simulation was run on the 75- by 30-cell grid described previously (Figure 6-22). The grid's spatial resolution was 500 ft in the on-offshore (x-) direction and 1,000 ft in the longshore (y-) direction for an overall grid size of 37,500 by 30,000 ft. It should be noted that the grid resolution between jetties is usually much finer (more cells) than what is used in these examples, in order to properly represent inlet hydrodynamics. The water depth in the back bay was held to a constant depth of 10 ft. The water depth varied from 30 ft along the shoreline cells to 300 ft at the offshore boundary. The duration of the simulation was 24 hr.

145. A tidal forcing function was implemented along the offshore boundary (T1) using harmonic constituent data (M2 tide, amplitude = 3.97 ft, epoch = 199.02 deg). Elevation values were spatially constant along the seaward boundary. Thus, all the seaward boundary cells acted as one entity, having the same time-series of water surface fluctuations. The tidal forcing function at the shoreline (T2) was identical to the offshore tidal forcing function, except for a 10-min phase lag. Elevation values along the

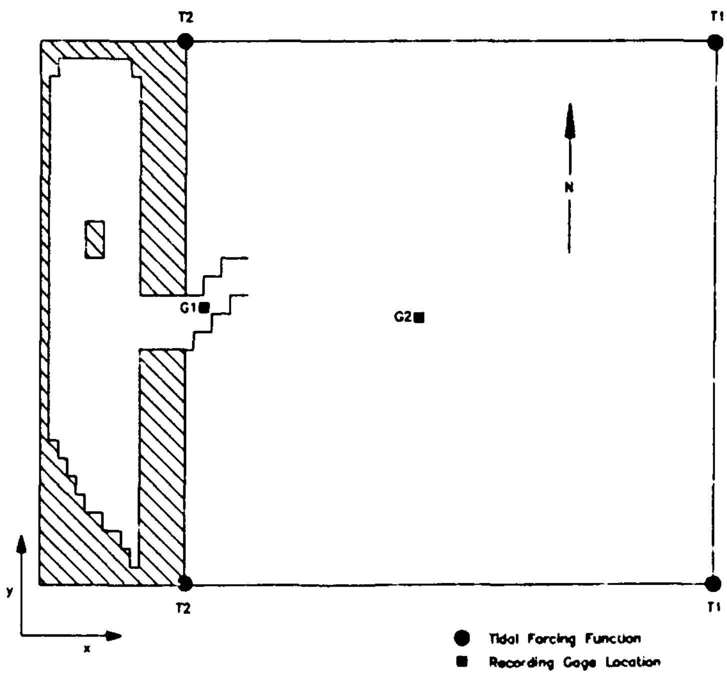

Figure 6-22. Computational area for tidal-forcing simulations

lateral boundary cells were interpolated from the two forcing functions (T1 and T2) applied at the ends of the boundary segment. Tide gages were placed at two locations: in the inlet (cell (19,16)) and in the open ocean (cell (42,15)) to monitor hydrograph data.

146. The input data set is given in Table 6-7 and is discussed below. The location and type of boundary forcing functions are specified with XBOUNDRY and YBOUNDRY records. FUNCTION, CNRECORD, and CONSTIT records give specifics about the two tidal forcing functions, such as the harmonic constituent(s) used, amplitude(s), epoch(s), and time(s) of occurrence. XBARRIER and YBARRIER records were used to denote the two jetties. Record BATHSPEC is used to describe the bathymetric data, and RECGAGE records show the locations of the two recording gages. The PRWINDOW record was used to print elevations and velocities for the entire grid to the output summary file at 1-hr time intervals (120 time-steps) (Table 6-8).

147. The simulation was run for 2,880 time-steps (24 hr), and elevation and velocity values were saved every 12 time-steps at the two recording gage locations. At the conclusion of the simulation, the hydrograph data were examined to check model results (Figures 6-23 and 6-24). The water surface elevation at the inlet gage shows a slight spurious oscillation at the start of the simulation, but the oscillation diminishes within one tidal cycle. This slight "start-up" error can be virtually eliminated by applying the tidal forcing function more gradually (feathering) or by starting the simulation at slack water. (See variable SELEV on record STARTUP.)

148. The water surface elevations at the open ocean gage oscillate with a very slight start-up error as previously described. The velocities at the open ocean gage travel in the x (90 deg) and -x (-90 deg) directions with a magnitude of approximately 1.3 ft/sec. The direction is dictated by the fact that the forcing function at the offshore boundary is spatially constant and the bathymetric contours are straight and parallel to the shoreline. The velocities through the inlet travel diagonally across the grid (45 and -135 deg) as directed by the jetties. The peak magnitude is approximately 2.5 ft/sec.

149. In summary, an M2 tide was simulated in a typical study environment to show CLHYD's ability to predict water surface fluctuations and velocities in response to the forcing function.

Table 6-7

Input Data Set for the Tidal-Forcing Simulation

```
GENSPECS      CLHYD SIMULATION NO. 1:  TIDE WITHOUT FEATHERING          ENGLISH
TIMESPEC      30. SECONDS        1     2880       12
GRIDSPEC          ENGLISH       75       30  37500.  30000.       1.
PRWINDOW                                         120                    EV
RECGAGE         19      16        INLET GAGE
RECGAGE         42      15        OCEAN GAGE
XBOUNDRYCONSTELV        75       1       30        1          BDRYX
YBOUNDRYINTRPELV         1      17       75        2        1 BDRY1
YBOUNDRYINTRPELV        30      17       75        2        1 BDRY2
FUNCTION          1HARMCNST
CNRECORD       0.0    1981       6        1      2.5
CONSTIT         M2    3.97  199.02
FUNCTION          2HARMCNST
CNRECORD       0.0    1981       6        1   2.6667
CONSTIT         M2    3.97  199.02
XBARRIER        18      14      14      2.5               XB1
XBARRIER        20      15      15      2.5               XB2
XBARRIER        22      16      16      2.5               XB3
XBARRIER        19      17      17      2.5               XB4
XBARRIER        21      18      18      2.5               XB5
YBARRIER        14      17      17      2.5               YB1
YBARRIER        15      18      19      2.5               YB2
YBARRIER        16      20      21      2.5               YB3
YBARRIER        17      22      23      2.5               YB4
YBARRIER        17      17      18      2.5               YB5
YBARRIER        18      19      20      2.5               YB6
YBARRIER        19      21      23      2.5               YB7
BATHSPEC                                         YX      (8X,9F8.1)
   1     -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0
         -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0
         -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0
         -99.0   -99.0   -99.0
   2     -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0    10.0
          10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0
          10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0
         -99.0   -99.0   -99.0
   3     -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0    10.0    10.0
          10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0
          10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0
          10.0   -99.0   -99.0
   4     -99.0   -99.0   -99.0   -99.0   -99.0   -99.0    10.0    10.0    10.0
          10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0
          10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0
          10.0   -99.0   -99.0
```

Table 6-8

Output Summary for the Tidal-Forcing Simulation

COASTAL MODELING SYSTEM (CMS): CLHYD , VERSION 1.0

— CLHYD SIMULATION NO. 1: TIDE WITHOUT FEATHERING —

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*				

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		*	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	75		*	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	30	
ALXREF	TOTAL LENGTH IN X DIRECTION	37500.00		*	ALYREF	TOTAL LENGTH IN Y DIRECTION	30000.00	

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	30.0		*	TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	SECONDS	
IT1	TIMESTEP AT START OF MODEL SIMULATIO	1		*	IT2	TOTAL NUMBER OF TIMESTEPS SIMULATED	2880	
NFREQ	TIMESTEP INTERVAL TO SAVE GAGE DATA	12		*	DTHOTS	TIMESTEP INTERVAL TO SAVE HOTSTARTS	0	

***** HYDROGRAPH AND VELOCITY MEASUREMENTS: 2 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	19	16				INLET GAGE
2	42	15				OCEAN GAGE

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER	*	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	*	TIMES TO PRINT (SECONDS): START AT	END AT	INTERVAL	NOTES:	*	VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1	*	X= 1	X= 75	Y= 1	Y= 30		*	0	2880	120		*	EV	

**** BATHSPEC CARD: SPECIFICATION OF BATHYMETRY/TOPOGRAPHY -

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
BUNITS	SYSTEM OF UNITS FOR DEPTH DATA	FEET		*	BSEQ	READ SEQUENCE FOR DEPTH DECK	YX	
WDATUM	DATUM FOR WATER DEPTHS	0.000		*	LDATUM	DATUM FOR LAND ELEVATIONS	0.000	
DLIMIT	MAXIMUM DEPTH ALLOWED	6000.0		*	BFORM	FORMAT OF DEPTH DATA	(8X,9F8.1)	

NUMBER OF ELEVATION CHANGES = 0

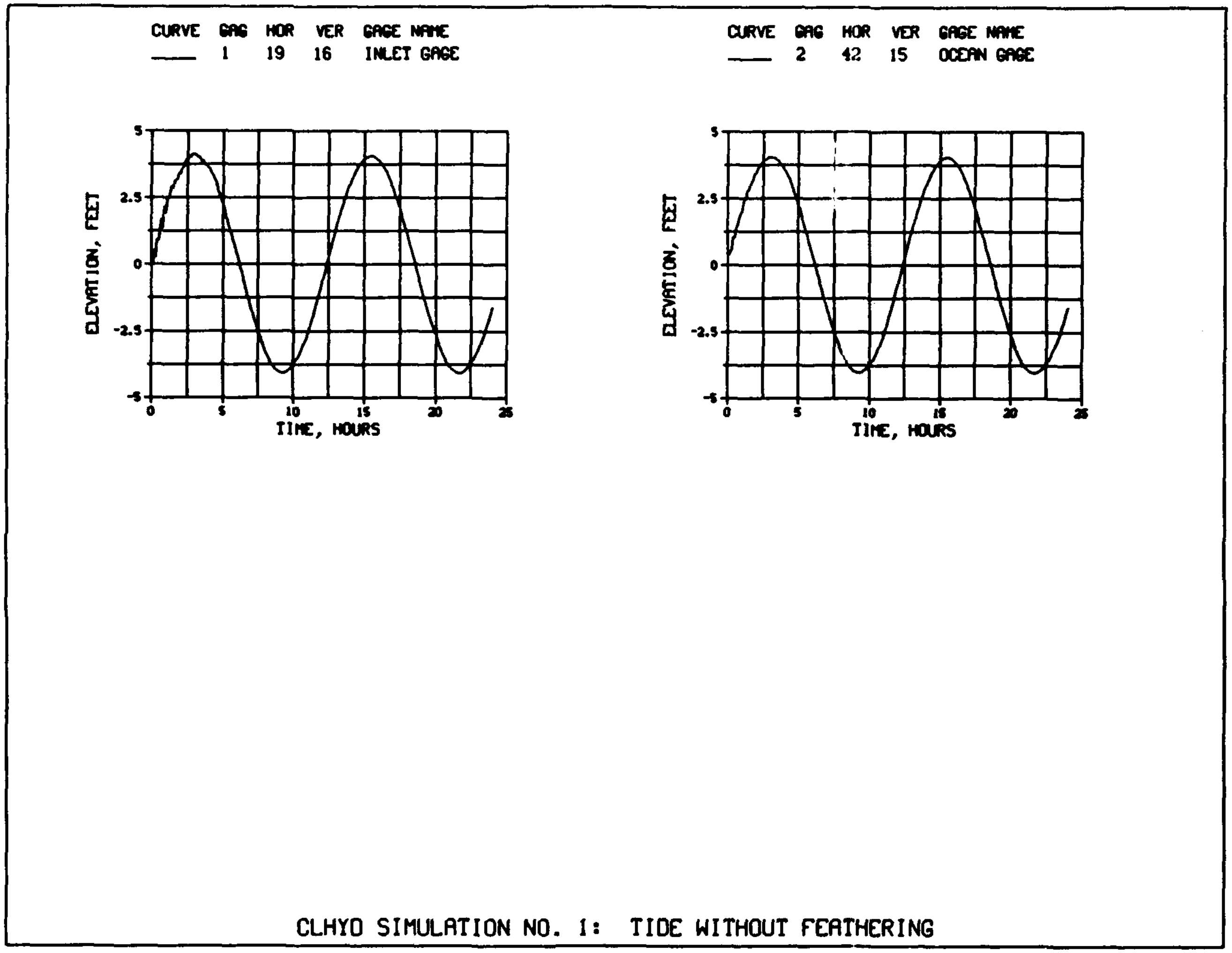

Figure 6-23. Elevation plots for the tidal-forcing simulation

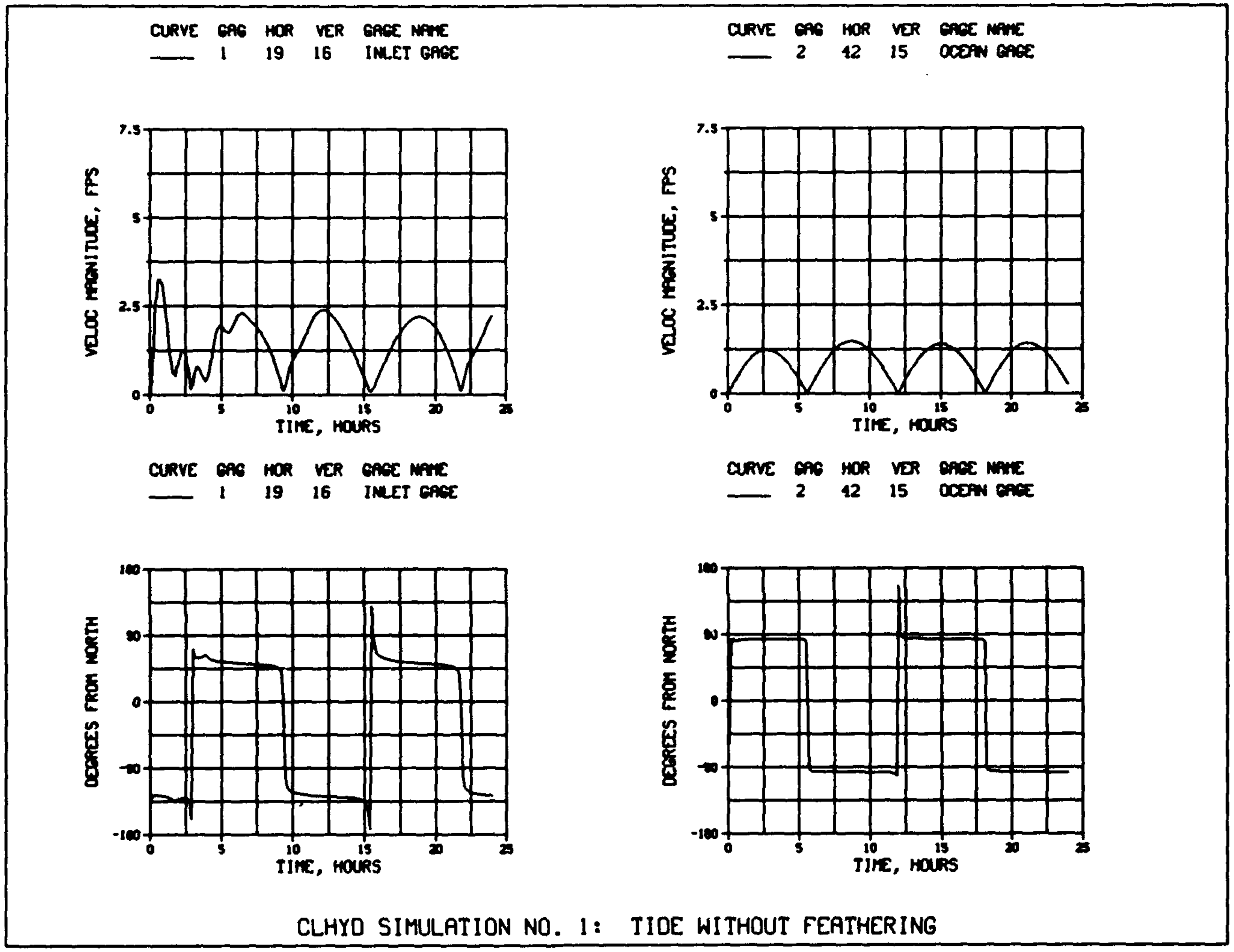

Figure 6-24. Velocity plots for the tidal-forcing simulation

Tidal-Forcing Simulation with Nonlinear Terms

150. The tidal-forcing simulation was repeated with the addition of records ADDTERMS and STARTUP. Record ADDTERMS is used to include advective and dispersion terms in the governing equations. The nonlinear terms are more difficult and time-consuming to simulate, but provide a more realistic representation of the hydrodynamics in the study area, particularly at the inlet where velocity gradients are greatest. Record STARTUP is used to raise the entire water surface to the peak flood elevation. At peak flood (or ebb), velocities reach zero, and the initial and boundary conditions are consistent. The "start-up" error observed in the last example can be reduced considerably with this procedure. Table 6-9 shows the addition of records ADDTERMS and STARTUP to the input data set. In addition, record PRWINDOW was modified to print elevations to the output file at the conclusion of the simulation only (Table 6-10).

151. The elevation and velocity hydrographs at the inlet and open ocean gages are presented in Figures 6-25 and 6-26. The elevations do not exhibit the degree of spurious oscillation observed in the first example. Starting the simulation at slack water considerably reduced the start-up error. The velocities also appear to be different from the velocities in the first example. The magnitude of the velocity at the open ocean gage is no longer equal on the ebb and flow because of the nonlinear terms. However, the direction of the velocity at the open ocean gage does not change significantly with the inclusion of nonlinear terms.

Wind-Induced Setup Simulation

152. In the third test simulation, a uniform wind was blown in the shoreward direction for the duration of the simulation (Figure 6-27). (The tidal forcing functions from the first simulation were also included.) The wind gradually increased over the first hour, until a maximum sustained wind speed of 40 knots was reached (Figure 6-28). Table 6-11 shows the addition of the WINDSPEC and TABWINDS records to the input data set to specify the gradually applied wind field. These records are used to describe the magnitude and direction of the wind field at designated times during the simulation. The PRWINDOW record was used to print elevations at hours 12 and 24 of

Table 6-9

Input Data Set for the Tidal-Forcing Simulation with Nonlinear Terms

```
GENSPECS     CLHYD SIMULATION NO. 2:  TIDE WITH NONLINEAR TERMS          ENGLISH
TIMESPEC     30. SECONDS       1    2520       12
GRIDSPEC         ENGLISH      75      30  37500.   30000.       1.
PRWINDOW                                    2520                        E
STARTUP    4.048
ADDTERMS      YES      YES     5.0     0.0
RECGAGE        19       16        INLET GAGE
RECGAGE        42       15        OCEAN GAGE
XBOUNDRYCONSTELV        75       1      30       1         BDRYX
YBOUNDRYINTRPELV         1      17      75       2       1 BDRY1
YBOUNDRYINTRPELV        30      17      75       2       1 BDRY2
FUNCTION        1HARMCNST
CNRECORD      0.0     1981       6       1     5.5
CONSTIT        M2     3.97  199.02
FUNCTION        2HARMCNST
CNRECORD      0.0     1981       6       1  5.6667
CONSTIT        M2     3.97  199.02
XBARRIER       18       14      14     2.5                 XB1
XBARRIER       20       15      15     2.5                 XB2
XBARRIER       22       16      16     2.5                 XB3
XBARRIER       19       17      17     2.5                 XB4
XBARRIER       21       18      18     2.5                 XB5
YBARRIER       14       17      17     2.5                 YB1
YBARRIER       15       18      19     2.5                 YB2
YBARRIER       16       20      21     2.5                 YB3
YBARRIER       17       22      23     2.5                 YB4
YBARRIER       17       17      18     2.5                 YB5
YBARRIER       18       19      20     2.5                 YB6
YBARRIER       19       21      23     2.5                 YB7
BATHSPEC                                     YX       (8X,9F8.1)
   1       -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0
           -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0
           -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0
           -99.0   -99.0   -99.0
   2       -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0    10.0
            10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0
            10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0
           -99.0   -99.0   -99.0
   3       -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0    10.0    10.0
            10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0
            10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0
            10.0   -99.0   -99.0
   4       -99.0   -99.0   -99.0   -99.0   -99.0   -99.0    10.0    10.0    10.0
            10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0
            10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0    10.0
            10.0   -99.0   -99.0
```

Table 6-10

Output Summary for the Tidal-Forcing Simulation with Nonlinear Terms

COASTAL MODELING SYSTEM (CMS): CLHYD , VERSION 1.0

---- CLHYD SIMULATION NO. 2: TIDE WITH NONLINEAR TERMS ----

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*				

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		*	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	75		*	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	30	
ALXREF	TOTAL LENGTH IN X DIRECTION	37500.00		*	ALYREF	TOTAL LENGTH IN Y DIRECTION	30000.00	

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	30.0		*	TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	SECONDS	
IT1	TIMESTEP AT START OF MODEL SIMULATIO	1		*	IT2	TOTAL NUMBER OF TIMESTEPS SIMULATED	2520	
NFREQ	TIMESTEP INTERVAL TO SAVE GAGE DATA	12		*	DTHOTS	TIMESTEP INTERVAL TO SAVE HOTSTARTS	0	

***** ADDTERMS CARD: SPECIFICATION OF ADDITIONAL TERMS IN GOVERNING EQUATIONS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
ADVFLAG	GOVERNS USE OF ADVECTION TERMS	YES		*	DIFFLAG	GOVERNS USE OF DIFFUSION TERMS	YES	
DIFCOF	DIFFUSION COEFFICIENT	5.0000		*	CORIOLIS	CORIOLIS COEFFICIENT	0.0000	

***** STARTUP CARD: SPECIFICATION OF INITIAL CONDITIONS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SELEV	INITIAL WATER SURFACE ELEVATION	4.05		*	SECHO	AMOUNT OF INPUT DATA TO BE PRINTED	SHORT	
IHOURO	HOUR AT START OF SIMULATION	0		*	IMINO	MINUTE AT START OF SIMULATION	0	
ISECO	SECOND AT START OF SIMULATION	0		*	SNAME	NAME OF STARTUP CONDITIONS		

***** HYDROGRAPH AND VELOCITY MEASUREMENTS: 2 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	19	16				INLET GAGE
2	42	15				OCEAN GAGE

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA * STARTING ENDING STARTING ENDING * TIMES TO PRINT (SECONDS): * VARIABLE FIELD

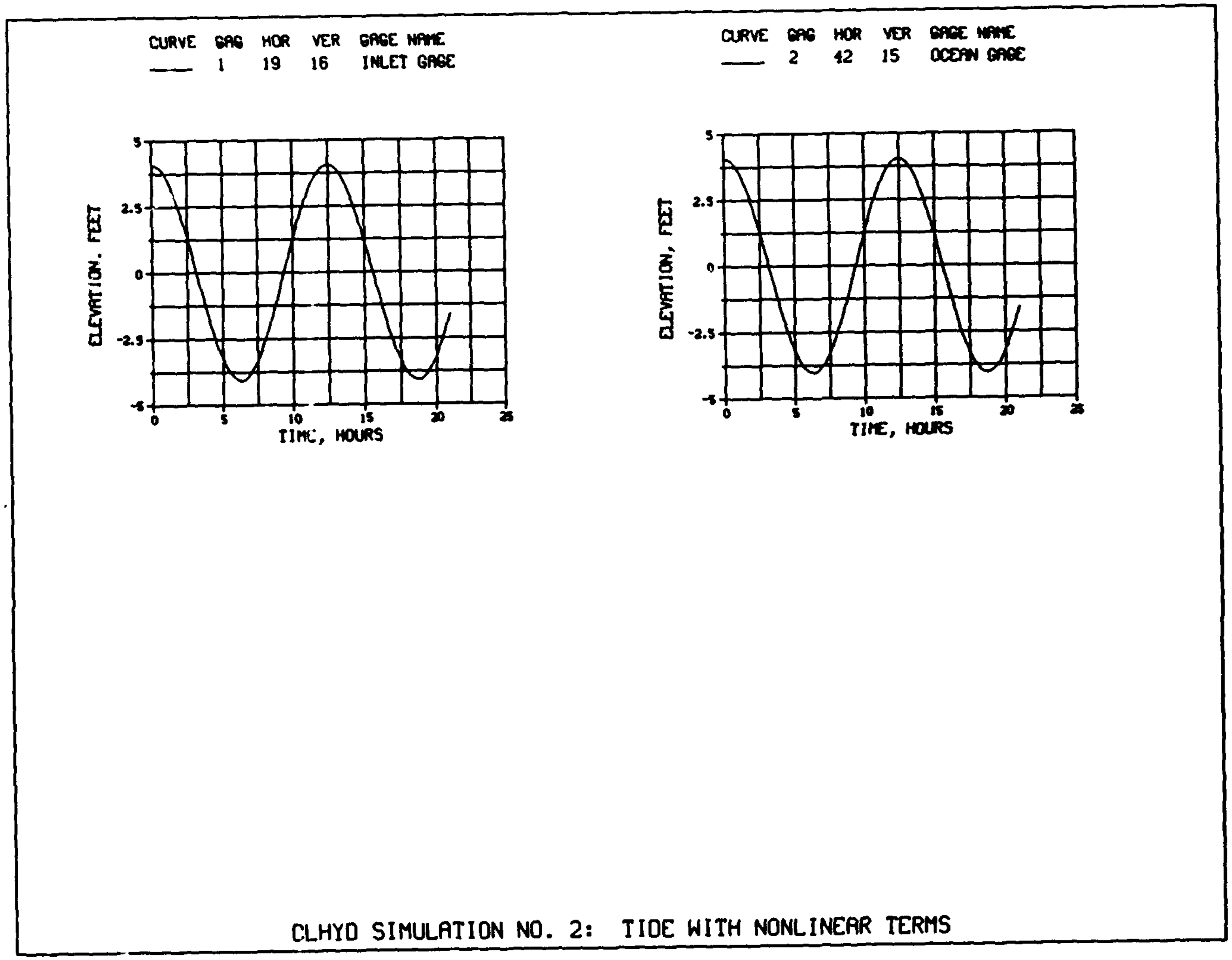

Figure 6-25. Elevation plots for the tidal-forcing simulation with nonlinear terms

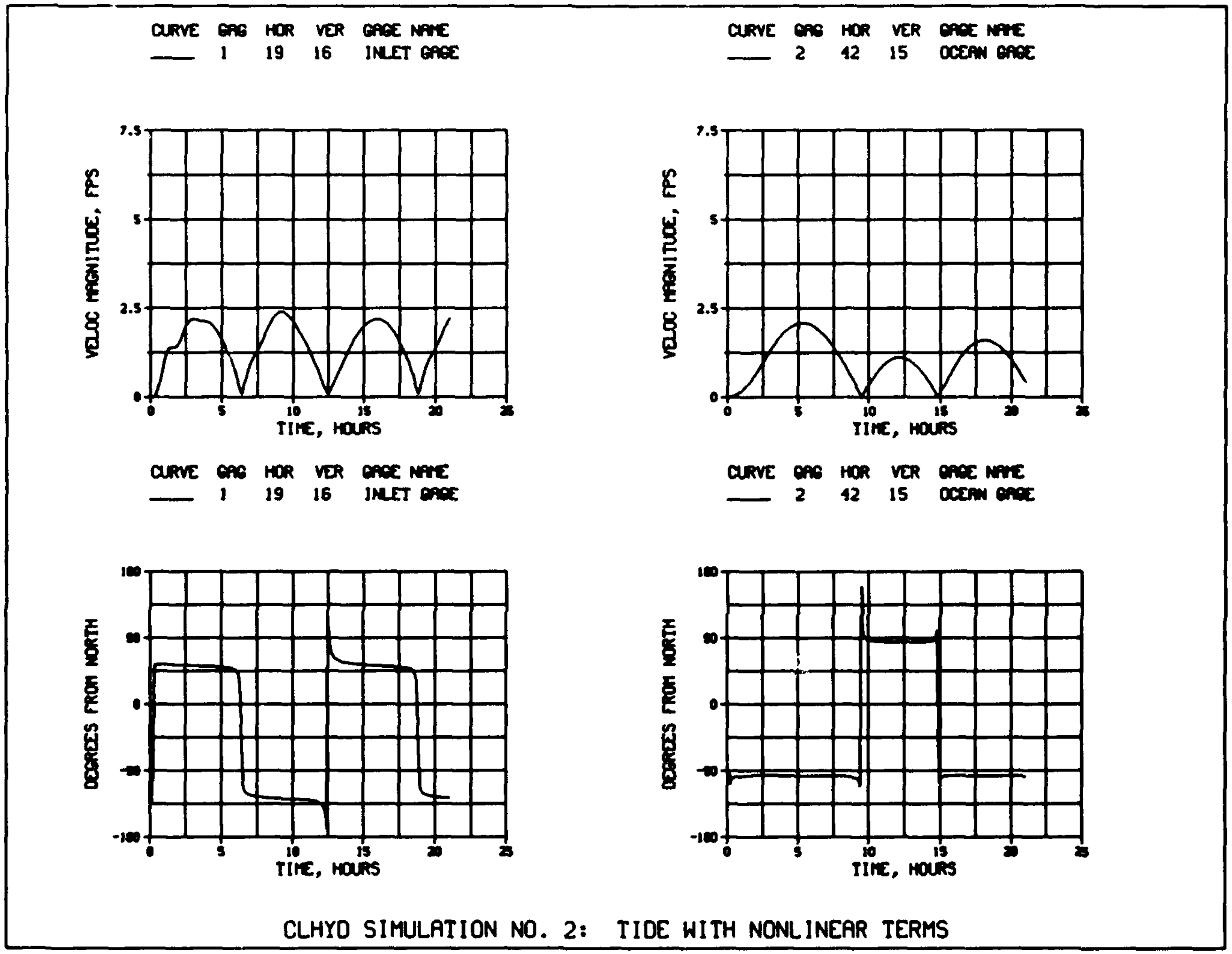

Figure 6-26. Velocity plots for the tidal-forcing simulation with nonlinear terms

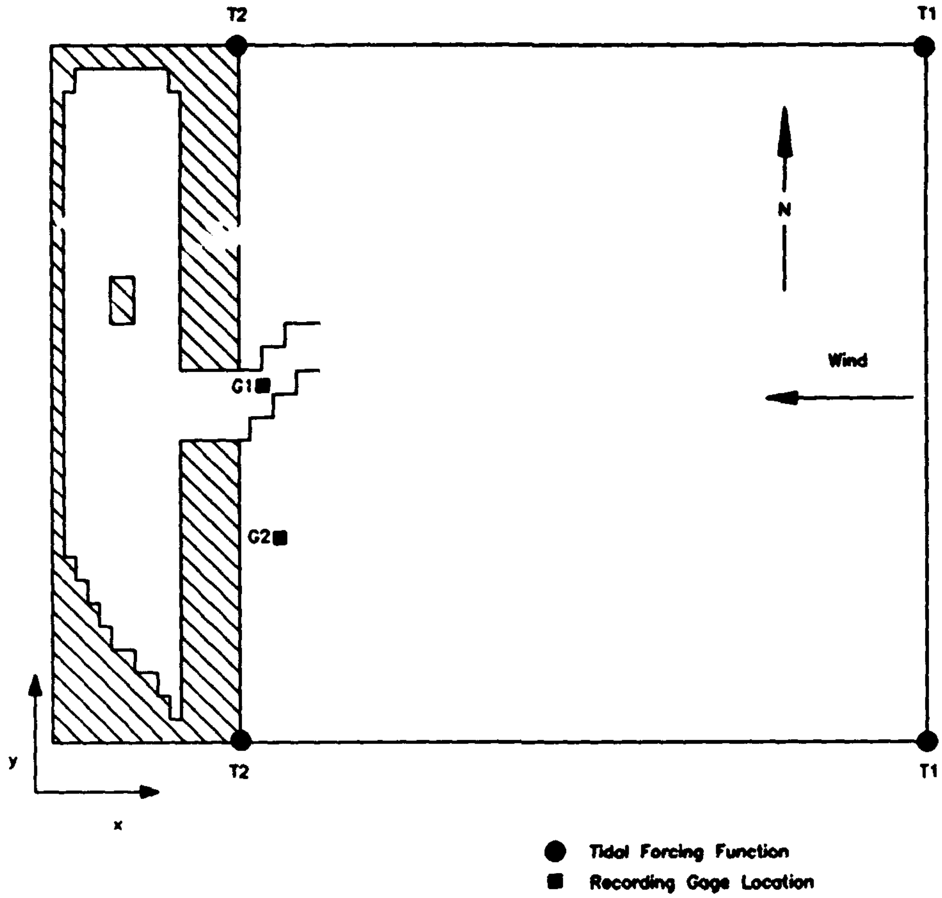

Figure 6-27. Computational grid for wind-induced setup simulation

the simulation (Table 6-12). The inlet and ocean hydrographs are presented in Figures 6-29 and 6-30 and are discussed below.

153. As the simulation proceeds, the wind continues to blow shoreward causing a setup to develop. From Figure 6-29, it appears that the elevations are the same for the tide with wind as with the tide alone. However, there is a slight rise in the mean water surface elevation. The magnitude of the velocity at the open ocean gage shows a larger peak ebb value than peak flood value. This larger peak ebb value is caused by the tide flow and the free surface gradient created by the onshore wind being in the same or opposite directions, respectively. (The water surface slope created by the onshore wind works against the onshore propagation of the tide wave.)

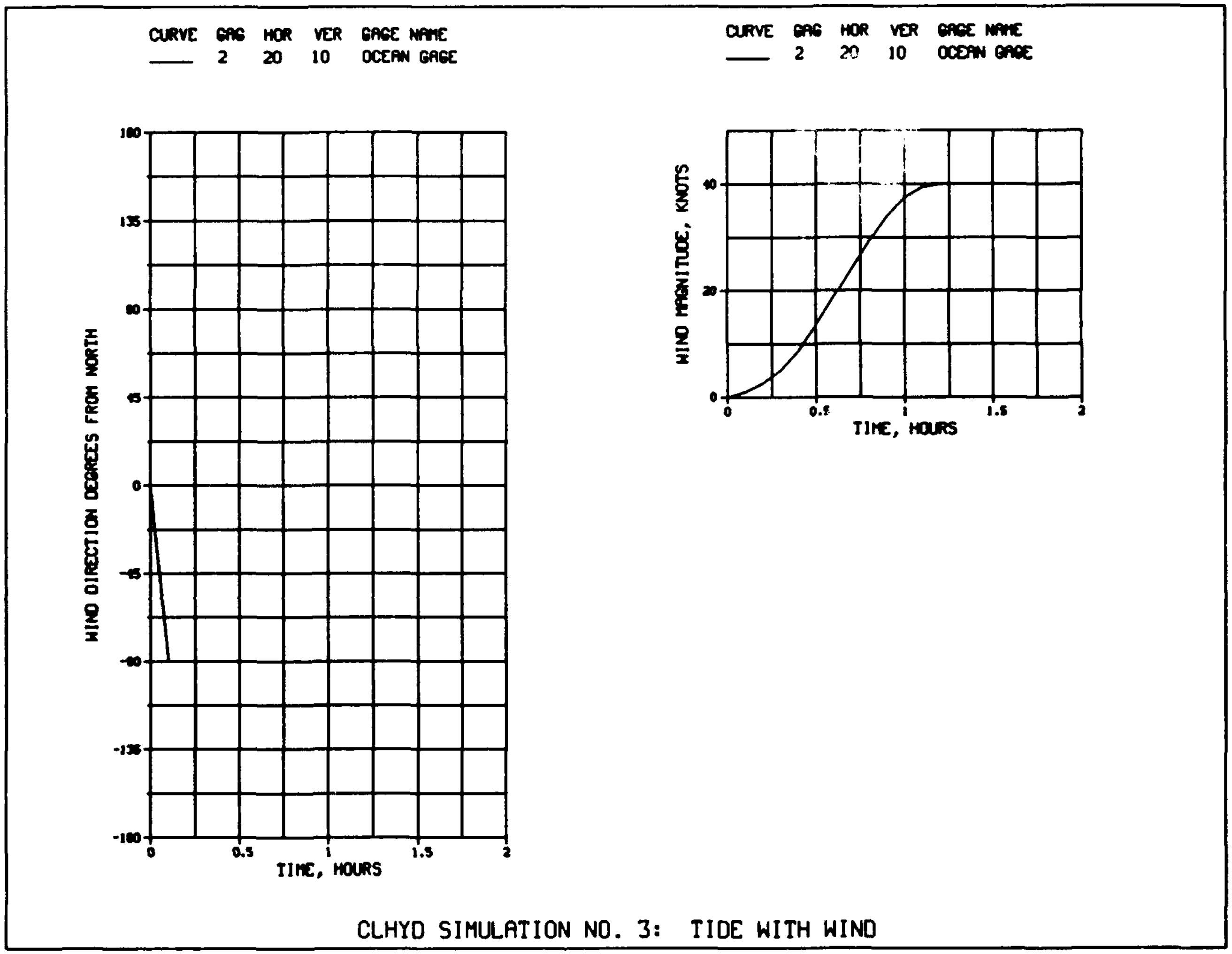

Figure 6-28. Wind magnitude and directions for wind-induced setup simulation

Table 6-11

Input Data Set for the Wind-Induced Setup Simulation

```
GENSPECS      CLHYD SIMULATION NO. 3:  TIDE WITH WIND                   ENGLISH
TIMESPEC      30. SECONDS       1     2880      12
GRIDSPEC          ENGLISH      75       30  37500.   30000.        1.
PRWINDOW                                     1440                      EV
WINDSPECTVRUNISP    KNOTS
TABWINDS          0       0     0.0     0.0
TABWINDS          0       6    -1.0     0.0
TABWINDS          0      10    -2.0     0.0
TABWINDS          0      16    -4.0     0.0
TABWINDS          0      20    -6.0     0.0
TABWINDS          0      26   -10.0     0.0
TABWINDS          0      42   -24.0     0.0
TABWINDS          0      50   -31.0     0.0
TABWINDS          0      54   -34.0     0.0
TABWINDS          0      58   -36.4     0.0
TABWINDS          1       2   -38.4     0.0
TABWINDS          1       6   -39.4     0.0
TABWINDS          1       8   -40.0     0.0
TABWINDS         24       0   -40.0     0.0
RECGAGE          19      16        INLET GAGE
RECGAGE          42      15        OCEAN GAGE
XBOUNDRYCONSTELV         75       1      30         1         BDRYX
YBOUNDRYINTRPELV          1      17      75         2       1 BDRY1
YBOUNDRYINTRPELV         30      17      75         2       1 BDRY2
FUNCTION           1HARMCNST
CNRECORD        0.0    1981       6       1       2.5
CONSTIT          M2    3.97  199.02
FUNCTION           2HARMCNST
CNRECORD        0.0    1981       6       1    2.6667
CONSTIT          M2    3.97  199.02
XBARRIER         18      14      14     2.5                       XB1
XBARRIER         20      15      15     2.5                       XB2
XBARRIER         22      16      16     2.5                       XB3
XBARRIER         19      17      17     2.5                       XB4
XBARRIER         21      18      18     2.5                       XB5
YBARRIER         14      17      17     2.5                       YB1
YBARRIER         15      18      19     2.5                       YB2
YBARRIER         16      20      21     2.5                       YB3
YBARRIER         17      22      23     2.5                       YB4
YBARRIER         17      17      18     2.5                       YB5
YBARRIER         18      19      20     2.5                       YB6
YBARRIER         19      21      23     2.5                       YB7
BATHSPEC                                       YX       (8X,9F8.1)
   1       -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0
           -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0
           -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0
           -99.0   -99.0   -99.0
```

Table 6-12
Output Summary for the Wind-Induced Setup Simulation

C O A S T A L   M O D E L I N G   S Y S T E M   (C M S) :   C L H Y D ,   V E R S I O N   1 . 0

— CLHYD SIMULATION NO. 3: TIDE WITH WIND —

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	* VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*			

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	* VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		* GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	75		* YCELL	NUMBER OF GRID CELLS, Y DIRECTION	30	
ALXREF	TOTAL LENGTH IN X DIRECTION	37500.00		* ALYREF	TOTAL LENGTH IN Y DIRECTION	30000.00	

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	* VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	30.0		* TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	SECONDS	
IT1	TIMESTEP AT START OF MODEL SIMULATIO	1		* IT2	TOTAL NUMBER OF TIMESTEPS SIMULATED	2880	
NFREQ	TIMESTEP INTERVAL TO SAVE GAGE DATA	12		* DTHOTS	TIMESTEP INTERVAL TO SAVE HOTSTARTS	0	

***** HYDROGRAPH AND VELOCITY MEASUREMENTS: 2 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	19	16				INLET GAGE
2	42	15				OCEAN GAGE

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER *	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	* TIMES TO PRINT (SECONDS): START AT	END AT	INTERVAL	NOTES:	* VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1 *	X= 1	X= 75	Y= 1	Y= 30		* 0	2890	1440		* EV	

***** WINDSPEC CARD: SPECIFICATION OF THE WIND FIELD -

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	* VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
WTYPE	FORM OF WIND FIELD DATA INPUT			* WNTRVL	WIND FIELD CONSTANT OR VARIABLE?	TVRUNISP	
WUNITS	WIND SPEED UNITS	KNOTS		* PUNITS	WINDFIELD NAME		

**** BATHSPEC CARD: SPECIFICATION OF BATHYMETRY/TOPOGRAPHY -

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	* VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:

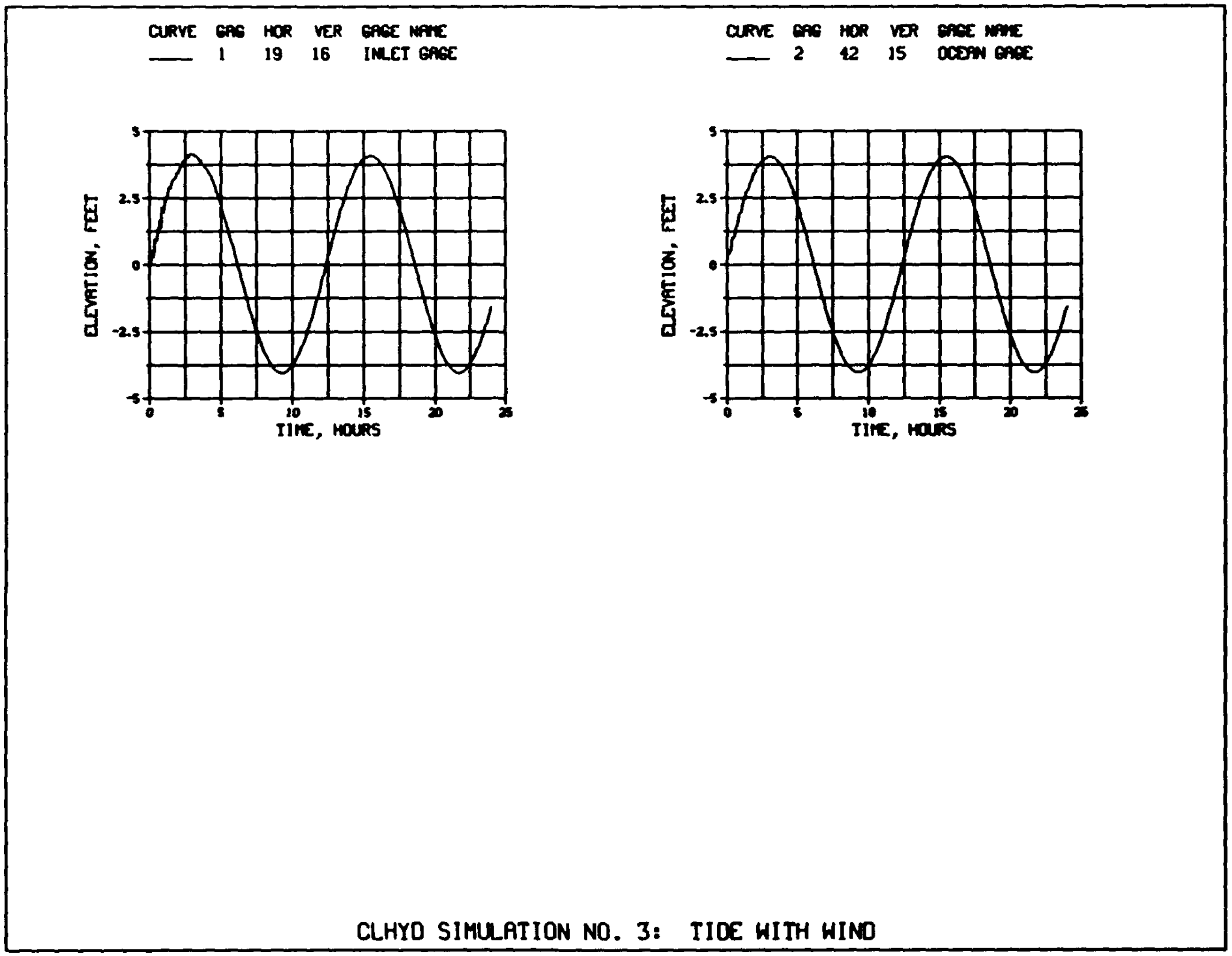

Figure 6-29. Elevation plots for the wind-induced setup simulation

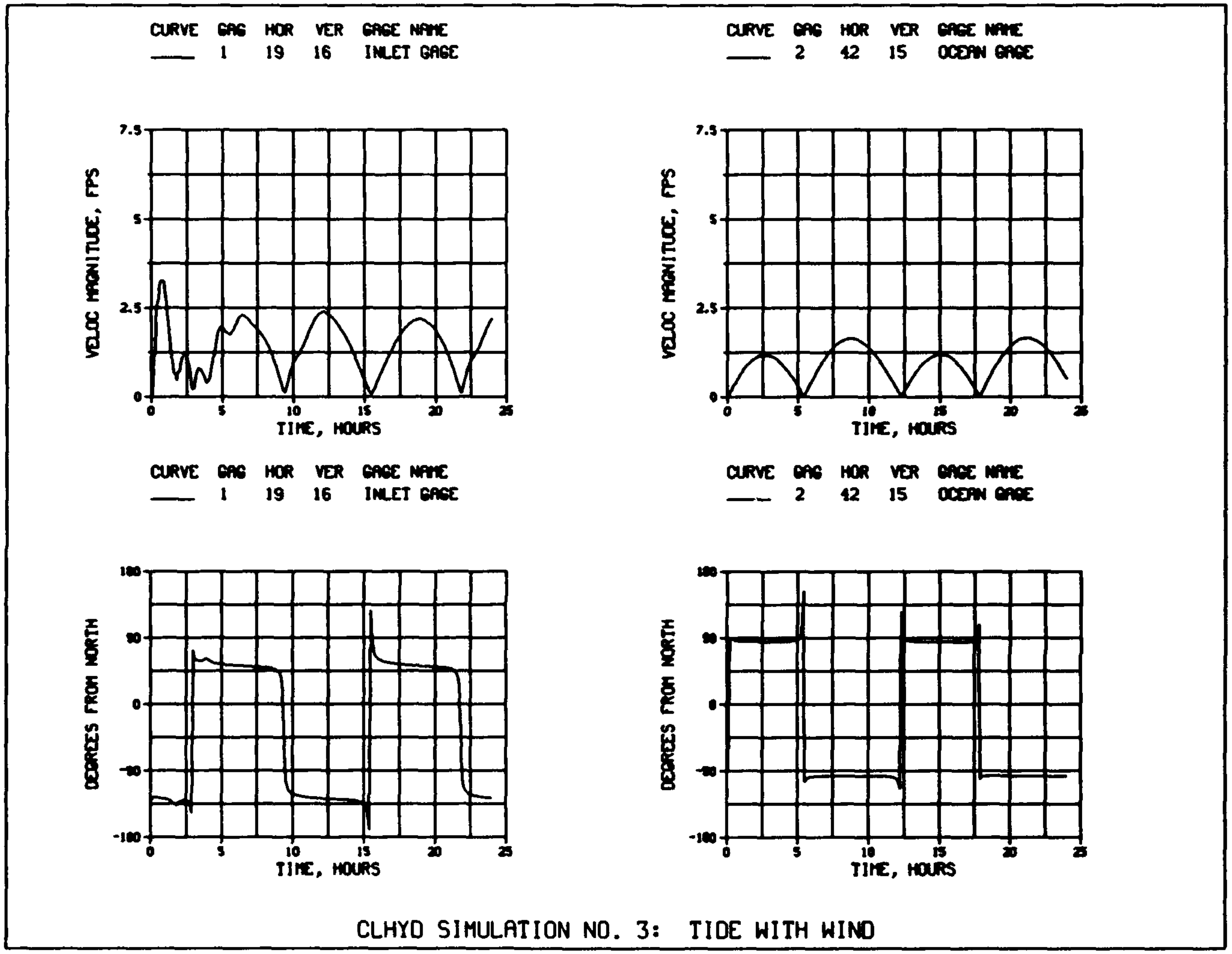

Figure 6-30. Velocity plots for the wind-induced setup simulation

River Discharge Simulation

154. In the fourth simulation, a river flowing into the back-bay area at a rate of 1,250 ft^3/sec was simulated (Figure 6-31). (The tidal forcing functions from the first simulation were also included.) The river inflow gradually increased over the first hour, until a maximum sustained flow rate of 1,250 ft^3/sec was reached. Table 6-13 shows the addition of a FUNCTION, TFRECORD, and several TABFLOW records to the input data set to specify the tabular flow forcing function. These records are used to specify inflow velocities at designated times during the simulation. An additional RECGAGE record was placed near the river mouth for monitoring purposes. The PRWINDOW record was used to print elevations at hours 12 and 24 for the simulation (Table 6-14). The inlet, ocean, and river hydrographs are presented in Figures 6-32 through 6-34 and are discussed below.

155. From Figure 6-32, it appears that the elevations at all three gages are dominated by the tidal forcing functions. The velocities at the open ocean and inlet gages are dominated by the tidal forcing (Figure 6-33); however, the river gage shows only a small oscillation caused by the tide (Figure 6-34). There is little evidence of the river inflow since the velocity is so small.

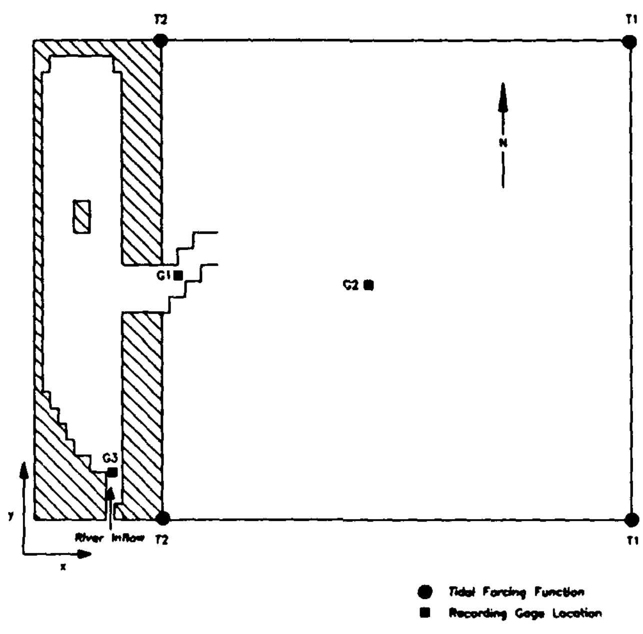

Figure 6-31. Computational grid for the river discharge simulation

Table 6-13

Input Data Set for the River Discharge Simulation

```
GENSPECS     CLHYD SIMULATION NO. 4:  TIDE WITH RIVER DISCHARGE            ENGLISH
TIMESPEC     30. SECONDS       1     2880      12
GRIDSPEC         ENGLISH      75       30   37500.  30000.      1.
PRWINDOW                                     1440                       E
RECGAGE        19       16        INLET GAGE
RECGAGE        42       15        OCEAN GAGE
RECGAGE        10        4        RIVER GAGE
XBOUNDRYCONSTELV        75         1       30       1          BDRYX
YBOUNDRYINTRPELV         1        17       75       2        1 BDRY1
YBOUNDRYINTRPELV        30        17       75       2        1 BDRY2
YBOUNDRYCONSTDIS         1        10       10       3          RIVER
FUNCTION        1HARMCNST
CNRECORD      0.0     1981         6        1     2.5
CONSTIT        M2     3.97    199.02
FUNCTION        2HARMCNST
CNRECORD      0.0     1981         6        1  2.6667
CONSTIT        M2     3.97    199.02
FUNCTION        3TABFLOWS
TFRECORD       14        3IRREGINT
TABFLOW        0.      0.0        0.      0.0
TABFLOW        0.      6.0        0. 0.00625
TABFLOW        0.     10.0        0.  0.0125
TABFLOW        0.     16.0        0.   0.025
TABFLOW        0.     20.0        0.  0.0375
TABFLOW        0.     26.0        0.  0.0625
TABFLOW        0.     42.0        0.    0.15
TABFLOW        0.     50.0        0. 0.19375
TABFLOW        0.     54.0        0.  0.2125
TABFLOW        0.     58.0        0.  0.2275
TABFLOW        1.      2.0        0.    0.24
TABFLOW        1.      6.0        0. 0.24625
TABFLOW        1.      8.0        0.    0.25
TABFLOW       24.      0.0        0.    0.25
XBARRIER       18       14        14     2.5                   XB1
XBARRIER       20       15        15     2.5                   XB2
XBARRIER       22       16        16     2.5                   XB3
XBARRIER       19       17        17     2.5                   XB4
XBARRIER       21       18        18     2.5                   XB5
YBARRIER       14       17        17     2.5                   YB1
YBARRIER       15       18        19     2.5                   YB2
YBARRIER       16       20        21     2.5                   YB3
YBARRIER       17       22        23     2.5                   YB4
YBARRIER       17       17        18     2.5                   YB5
YBARRIER       18       19        20     2.5                   YB6
YBARRIER       19       21        23     2.5                   YB7
BATHSPEC                                         YX       (8X,9F8.1)
    1     -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0
          -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0
          -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0   -99.0
```

Table 6-14

Output Summary for the River Discharge Simulation

COASTAL MODELING SYSTEM (CMS): CLHYD , VERSION 1.0

---- CLHYD SIMULATION NO. 4: TIDE WITH RIVER DISCHARGE ----

***** GENSPECS CARD: SPECIFICATION OF TITLE AND GENERAL SYSTEM OF UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
SUNITS	UNITS SYSTEM USED IN COMPUTATIONS	ENGLISH		*				

***** GRIDSPEC CARD: SPECIFICATION OF THE TYPE OF FINITE-DIFFERENCE GRID USED

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
GRTYPE	TYPE OF FINITE-DIFFERENCE GRID	RECTANG		*	GUNITS	SYSTEM OF UNITS USED FOR THE GRID	ENGLISH	
XCELL	NUMBER OF GRID CELLS, X DIRECTION	75		*	YCELL	NUMBER OF GRID CELLS, Y DIRECTION	30	
ALXREF	TOTAL LENGTH IN X DIRECTION	37500.00		*	ALYREF	TOTAL LENGTH IN Y DIRECTION	30000.00	

***** TIMESPEC CARD: SPECIFICATION OF COMPUTATIONAL TIME UNITS

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
DELT	COMPUTATIONAL TIME STEP (SECONDS)	30.0		*	TUNITS	TIME UNITS FOR ALL INPUT VARIABLES	SECONDS	
IT1	TIMESTEP AT START OF MODEL SIMULATIO	1		*	IT2	TOTAL NUMBER OF TIMESTEPS SIMULATED	2880	
NFREQ	TIMESTEP INTERVAL TO SAVE GAGE DATA	12		*	DTHOTS	TIMESTEP INTERVAL TO SAVE HOTSTARTS	0	

***** HYDROGRAPH AND VELOCITY MEASUREMENTS: 3 GAGES

GAGE NUMBER:	GAGE-POSITION X	Y	NOTES:	VELOCITY-MEASUREMENT TYPE:	NOTES:	GAGE NAME:
1	19	16		INLET GAGE		
2	42	15		OCEAN GAGE		
3	10	4		RIVER GAGE		

***** PRINTING OF FIELD ARRAY VARIABLES: 1 AREAS

AREA NUMBER	*	STARTING X CELL	ENDING X CELL	STARTING Y CELL	ENDING Y CELL	NOTES:	*	TIMES TO PRINT (SECONDS): START AT	END AT	INTERVAL	NOTES:	*	VARIABLE FIELD ARRAYS TO PRINT:	NOTES:
1	*	X= 1	X= 75	Y= 1	Y= 30		*	0	2880	1440		*	E	

**** BATHSPEC CARD: SPECIFICATION OF BATHYMETRY/TOPOGRAPHY -

VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:	*	VARIABLE	DESCRIPTION OF USAGE:	VALUE:	NOTES:
BUNITS	SYSTEM OF UNITS FOR DEPTH DATA	FEET		*	BSEQ	READ SEQUENCE FOR DEPTH DECK	YX	
WDATUM	DATUM FOR WATER DEPTHS	0.000		*	LDATUM	DATUM FOR LAND ELEVATIONS	0.000	
DLIMIT	MAXIMUM DEPTH ALLOWED	6000.0		*	BFORM	FORMAT OF DEPTH DATA	(8X,9F8.1)	

NUMBER OF ELEVATION CHANGES = 0

**** BARRIER CARD: SPECIFICATION OF LOCATION AND CHARACTERISTICS OF SUBGRID-SCALE BARRIER

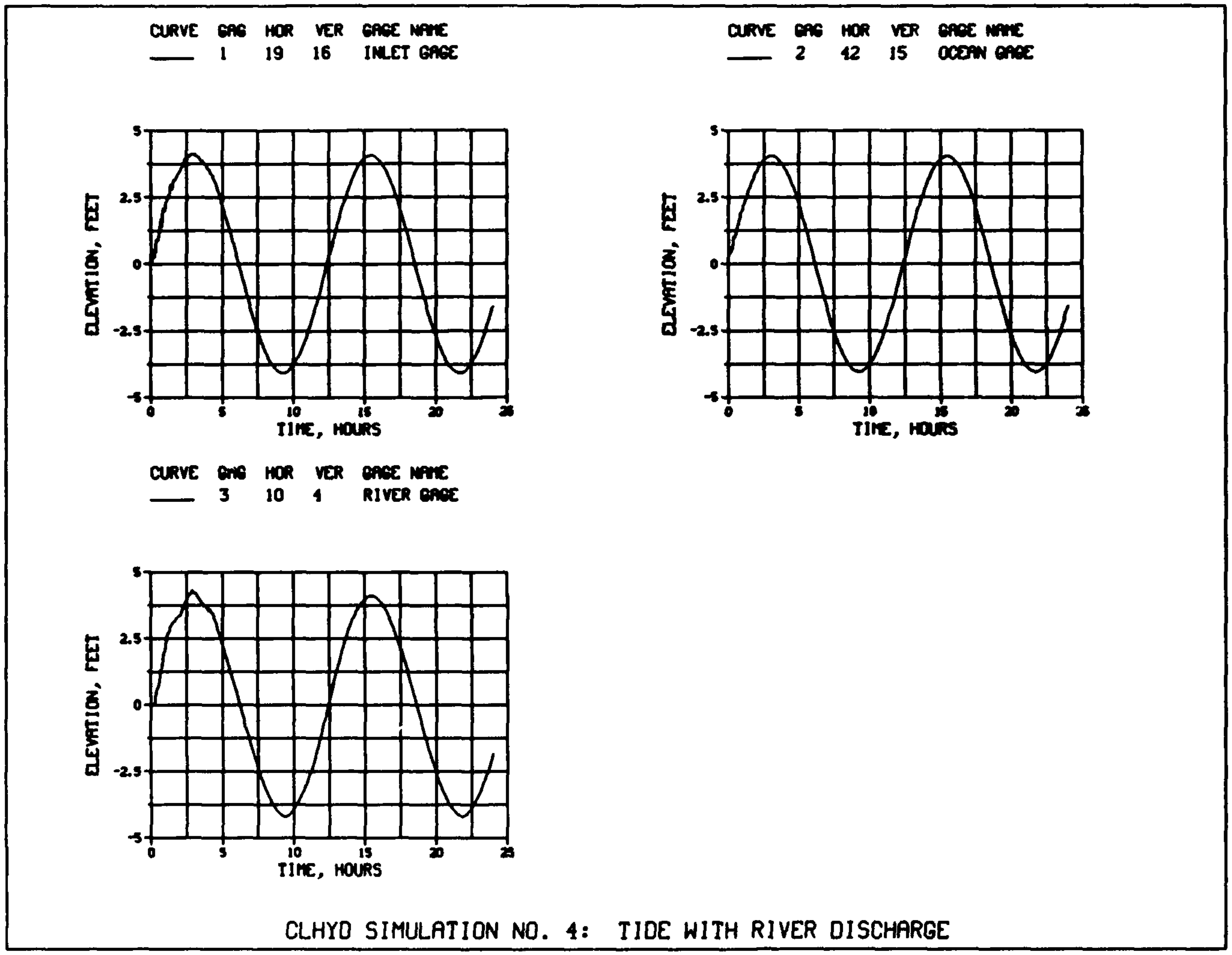

Figure 6-32. Elevation plots for the river discharge simulation

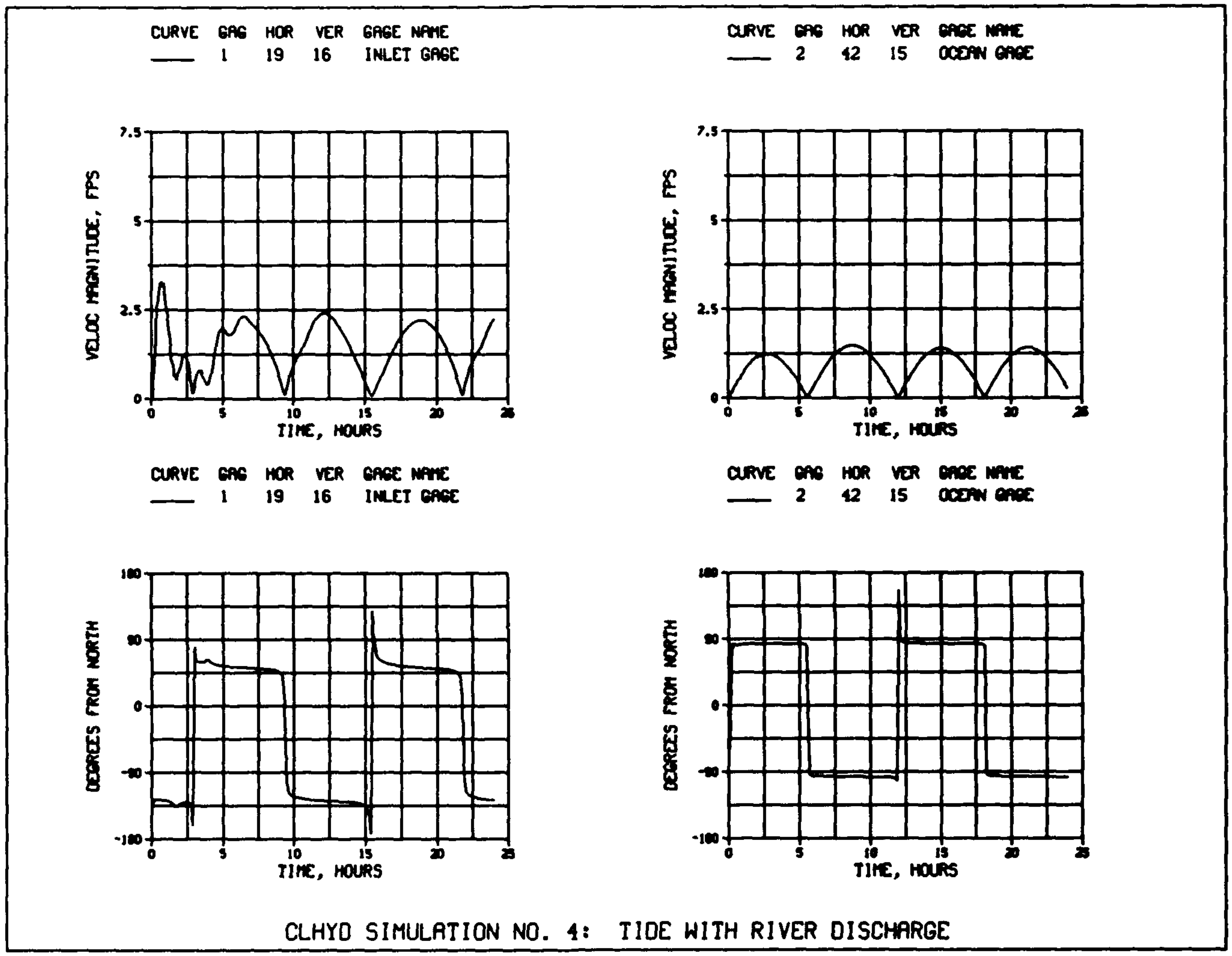

Figure 6-33. Velocity plots for the wind-induced setup simulation, gages 1 and 2

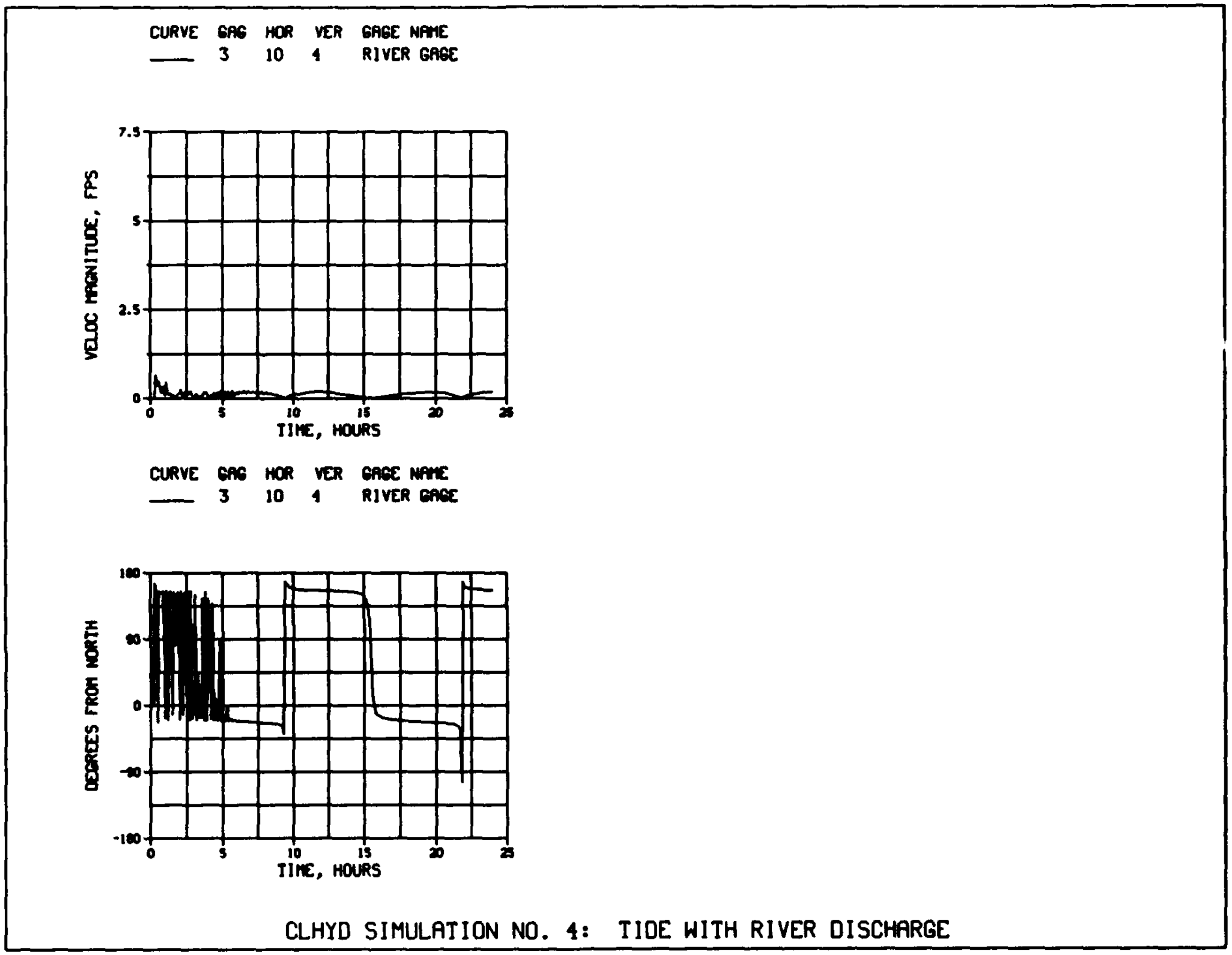

Figure 6-34. Velocity plot for the wind-induced setup simulation, gage 3

Orthogonal Curvilinear Grid Test Series

156. A second series of tests were conducted using an orthogonal curvilinear grid system. As is the case with a rectangular grid system, this grid represents a subset of a generalized curvilinear grid system. The governing equations for an orthogonal curvilinear grid have more nonzero transformation terms in the governing equations than a rectangular grid, but the equations are not the "full" equations used in the case of a generalized curvilinear grid system.

157. The basin geometry for this series of tests is a section of a circular annulus. Analytic solutions that describe the response of this type of basin to wind and tidal forcing are available (Lynch and Gray 1978). The annular section and corresponding grid used in the test series are presented in Figure 6-35. The inner radius of the annulus is 20,000 ft and the outer radius is 100,000 ft. An arc of 42 degrees is subtended between the lateral boundaries. The grid contains 20 cells in the radial direction and 14 cells in the angular direction. The tests presented in this series include: static basin, wind induce setup, and tidal forcing simulations followed by a series of grid resolution tests.

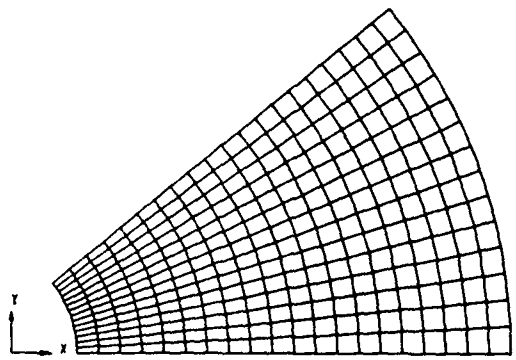

Figure 6-35. Annular section

Static Basin Tests

158. The static basin test is as important as it is simple. In such a test, no external forces are applied to an enclosed basin of fluid. The basin is expected to remain at rest; that is, no velocities should be generated, and

the water surface should remain at its initial level. If these conditions are met, then the boundary conditions and forces in the momentum equations are formulated properly.

159. The basin geometry for these tests was described above. The water depth in each grid cell was set equal to 30.0 ft. The initial water surface displacement throughout the grid was set to 0.0 ft in the first test and 1.0 ft in the second test. The length of the simulation was 20 hr, or 1,200 time-steps, with each time-step representing 60 sec. Figures 6-36 and 6-37 show the water surface displacement as a function of time for the two static tests. Any changes in the water surface elevation would indicate that the model has a problem with the formulation of the boundary conditions or forces in the momentum equations. The water surface elevation results sl ^w that the model is properly formulated.

160. The numerical value of the velocities remained zero for the simulation with an initial surface displacement of zero. However, the numerical value of the velocities in the second test were on the order of 10^{-16} fps. All tests were performed on a VAX 11/750 computer, which operates with a 32-bit processor. These tests were run using double precision; therefore, the value of the velocities are of the same order of magnitude as the maximum number of significant digits for a 64-bit processor. It is, therefore, concluded that the small velocities produced by the model are caused by round-off errors inherent to the computer itself. If there had truly been a problem with mass conservation, then the velocities would most likely have been much greater and the free surface would have changed from its initial level. The success of these tests indicates that the model performs correctly for an orthogonal curvilinear grid system.

Wind-Induced Setup Tests

161. When a steady, uniform wind is applied to an enclosed basin, the water surface will tilt (or setup) in the direction of the wind. Such a test was performed on the annular basin. Three simulations were made using the annular basin with uniform depth, each characterized by a different wind direction: parallel to the x-axis, the y-axis, and the centerline of the basin. A wind stress of 0.07 lb/ft^2 was held constant for all three tests. Regardless of the configuration of the basin, at steady state conditions the

water surface should be linearly varying in the direction of the wind since the depth is constant. In other words, the water surface elevation contours should be straight lines which are perpendicular to the wind direction.

162. Each simulation was performed for 1440 timesteps of 60 sec each for a total simulation time of 24 hrs. Figures 6-38 through 6-40 show the

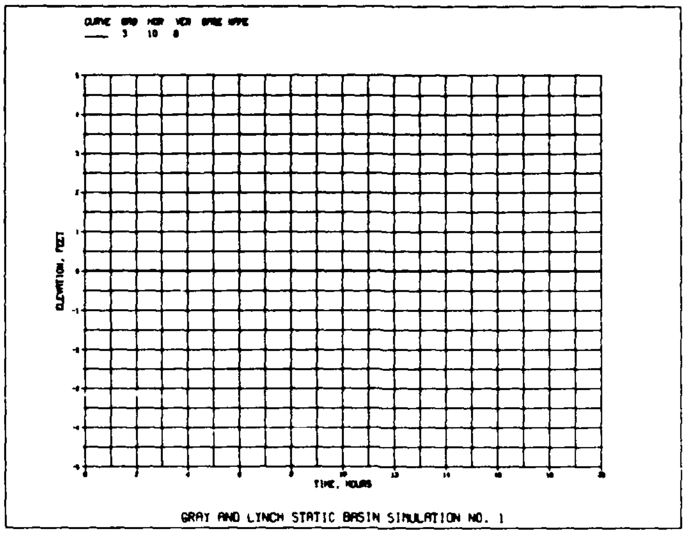

Figure 6-36. Static basin test 1

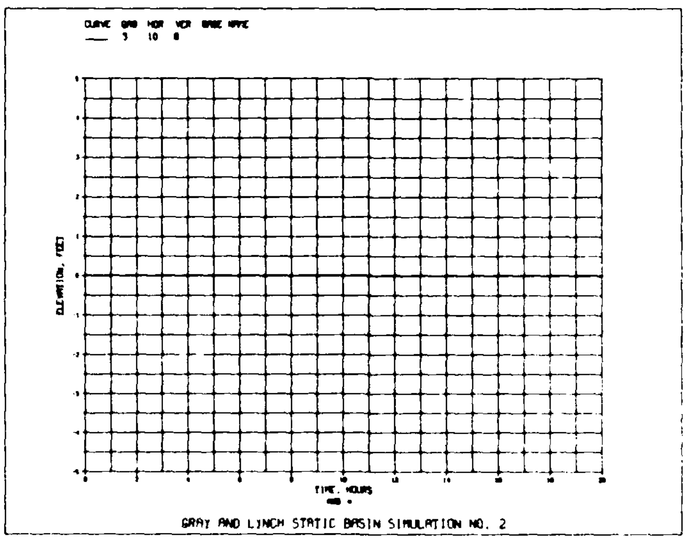

Figure 6-37. Static basin test 2

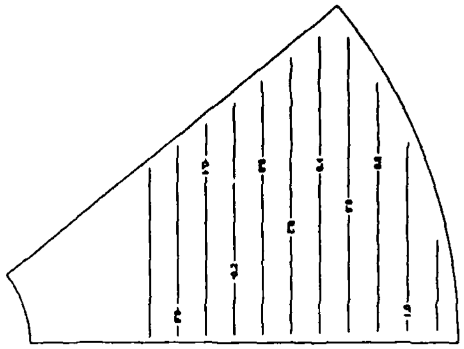

Figure 6-38. Wind-induced set-up test 1

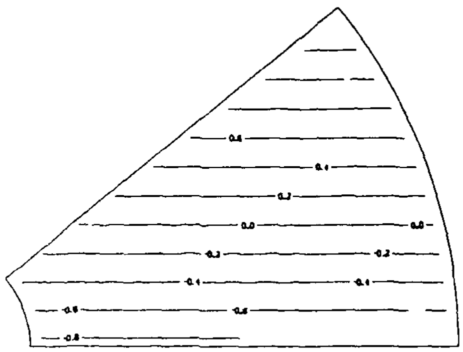

Figure 6-39. Wind-induced set-up test 2

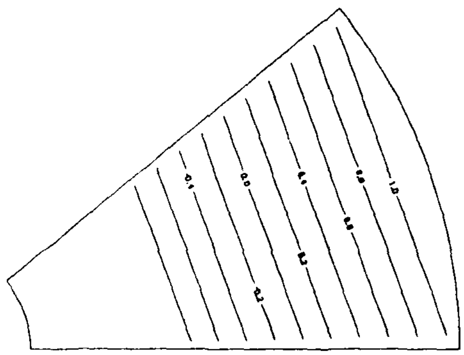

Figure 6-40. Wind-induced set-up test 3

contours of the water surface elevation at steady-state. In all three cases the contours are straight and perpendicular to the wind direction. The magnitude of the water surface slope is as predicted when studying the balance of momentum in the direction of the wind.

Tidal-Forcing Test

163. Lynch and Gray (1978) derived analytic solutions that describe the hydrodynamics created by a tidal forcing along the outer radial boundary of an annular section, with the remaining three boundaries closed. As in the case of a rectangular basin, a standing wave pattern is created in the annular-shaped basin. In their derivation, Lynch and Gray assumed bottom friction was a linear function of the water depth. In order to compare results with the "analytic" solution, the model CLHYD was modified to use linear, rather than the typically used nonlinear, bottom friction formulation.

164. In the tidal forcing simulation, the water depth was constant (30.0 ft) throughout the basin. Each simulation was run for 5,760 time-steps of 60 sec each, for a total simulation time of 96 hr (4 days). Initial flow field parameters were set equal to the values predicted by the analytic solution at time $t = 2{,}700$ sec (slightly after high tide when the velocities are small). The linear bottom friction coefficient was 6.0×10^{-6} in each simulation. The ratio of the radial grid dimension to the tidal wavelength, $\Delta r/L$, was approximately 1/170.

165. Figures 6-41 and 6-42 show comparisons between simulated water surface displacements (solid lines) and the analytic solution (dashed lines) as a function of time at five locations within the grid. Gages 1 and 5 show results at the closed and open ends of the basin, respectively. The model results at gage 5 are, in fact, the forcing function used to drive the model hydrodynamics, i.e., the analytic solution. From Figures 6-41 and 6-42, it is shown that the agreement between the model and the exact solution is good.

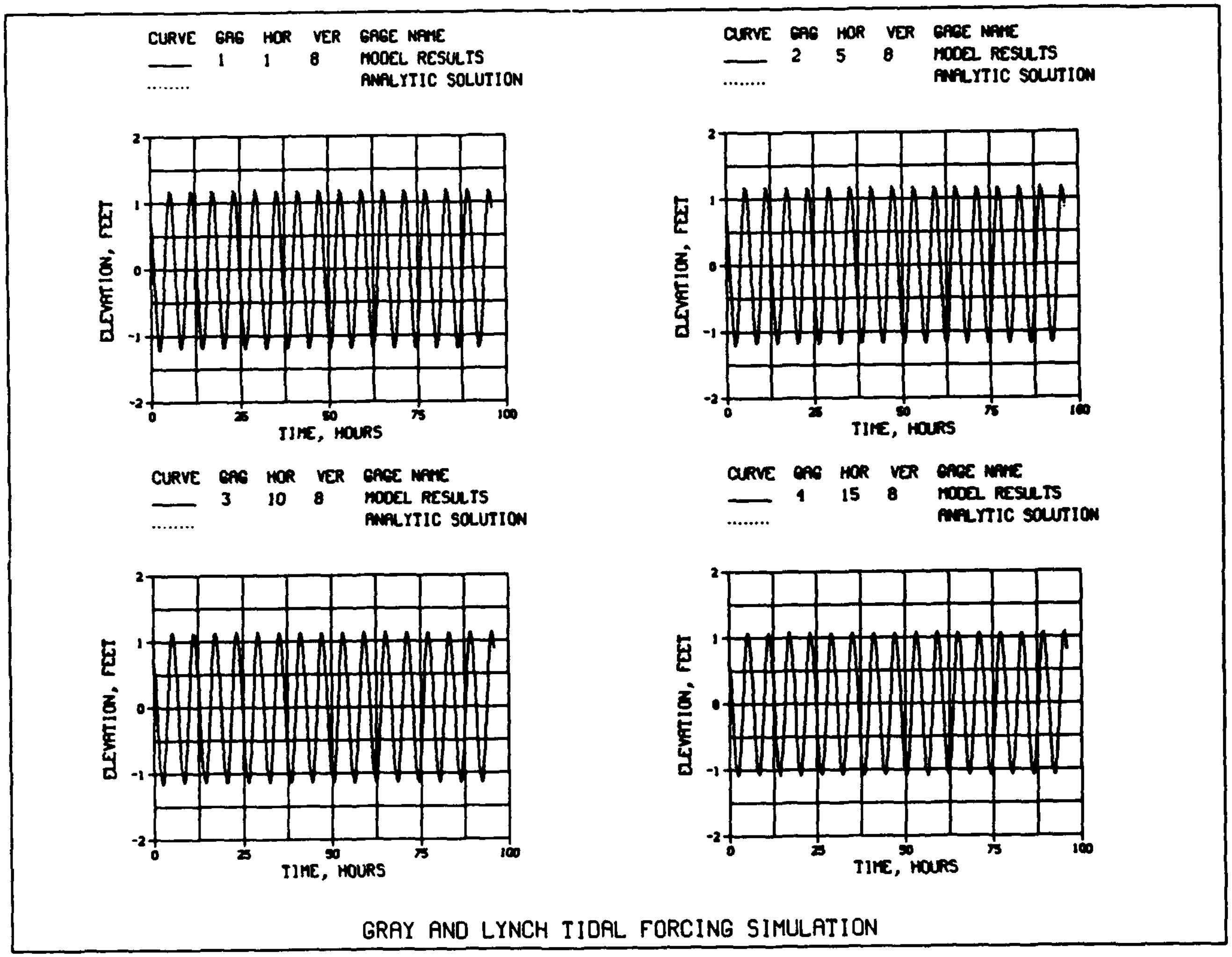

Figure 6-41. Comparisons between model results and analytic solution, gages 1 through 4

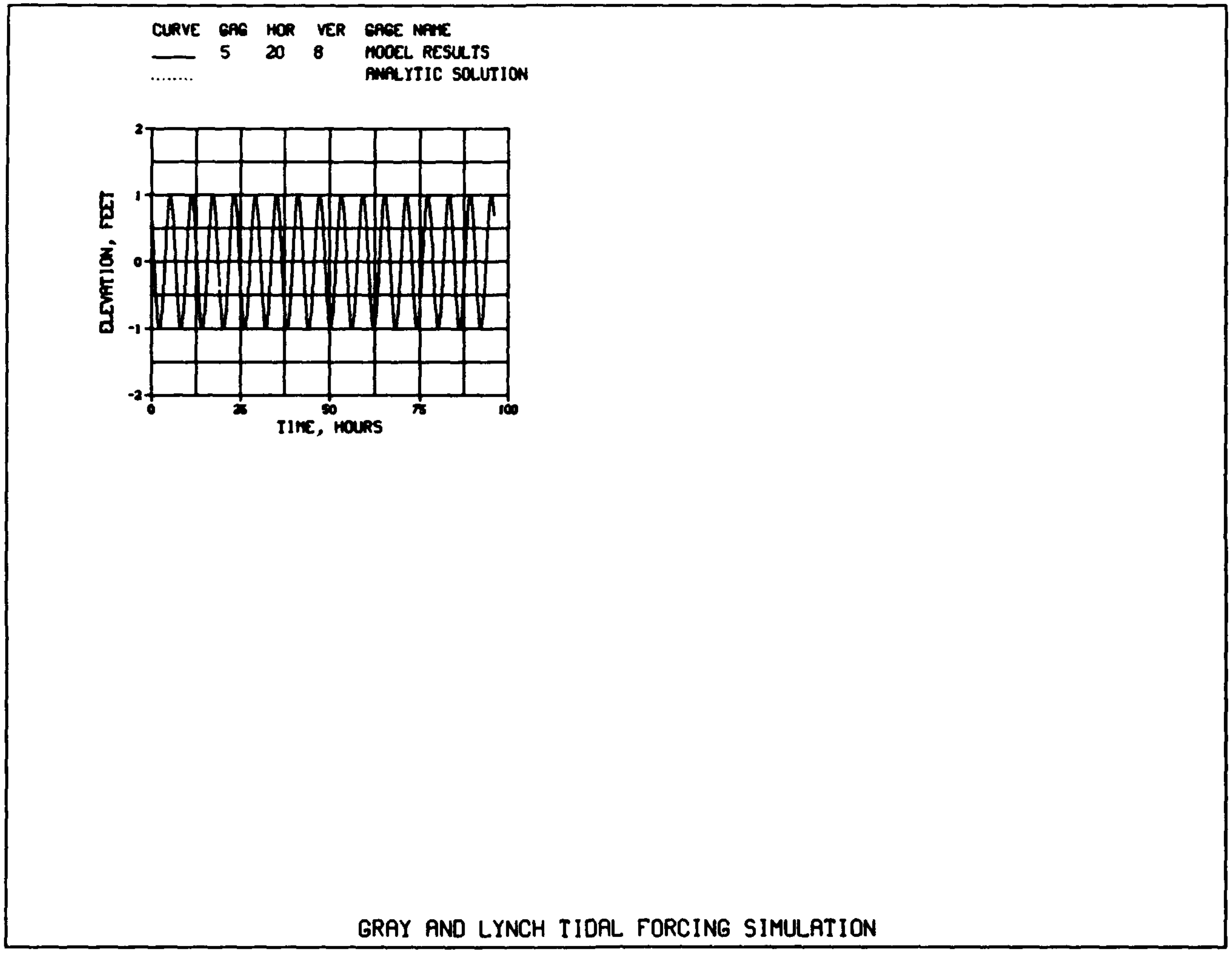

Figure 6-42. Comparison between model results and analytic solution, gage 5

Grid Resolution Tests Using Orthogonal Curvilinear Grids

166. To simulate wave propagation correctly, CLHYD must be able to resolve a fluid particle moving from one cell to the next. The travel time of the particle defines the minimum time interval between successive numerical solutions of the governing equations (the time-step). Since the travel time of the particle is dependent on the cell width as well as the wave celerity, the time-step is also a function of these parameters. For ADI schemes, such as in CLHYD, the ratio of the distance traveled by a water particle in one time-step to the grid cell size should be restricted to a maximum value of approximately 5. This ratio, referred to as the Courant number, is presented below:

$$C_r = \frac{\Delta t\sqrt{gH}}{\Delta x} \tag{6-48}$$

where

Δt = time-step size

g = gravitational acceleration

H = water depth

Δx = grid cell width

C_r = Courant number

167. The significance of the time- and space-steps, or essentially the Courant condition, was investigated in the following series of tests. A set of nine tidal forcing simulations were conducted in the annular test basin. In each test, the water depth was constant (30 ft) throughout the basin, the inner radius was set to 20,000 ft, and the outer radius was set to 100,000 ft. To investigate model accuracy, simulations with various grid resolutions and time-steps were conducted. The grids ranged from a 20 x 14 grid (Δr = 4,000 ft), where Δr is the radial grid dimension, to a 8 x 7 grid (Δr = 10,000 ft), to an extremely coarse resolution 4 x 7 grid (Δr = 20,000 ft) (Figures 6-43 through 6-45). The $\Delta r/L$ ratio thus ranged from 1/170 to 1/35. Typically long-wave simulations involve $\Delta r/L$ ratios smaller than 1/170, but the objective of this test series was to test the extremes to which the model can be used.

168. The actual distance between the tidal boundary and the far end of the basin differed for each grid because the tidal boundary condition is

applied at the center of each of the outer radial cells. Thus, a wave would travel a different distance to reach the far end of the basin in each of the three grids. Therefore, the selected tidal period varied for the three basins

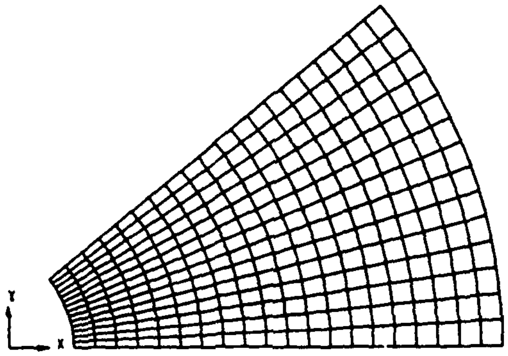

Figure 6-43. Annular section grid no. 1 (20 x 14)

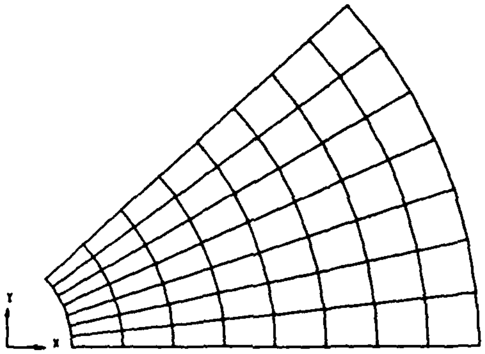

Figure 6-44. Annular section grid no. 2 (8 x 7)

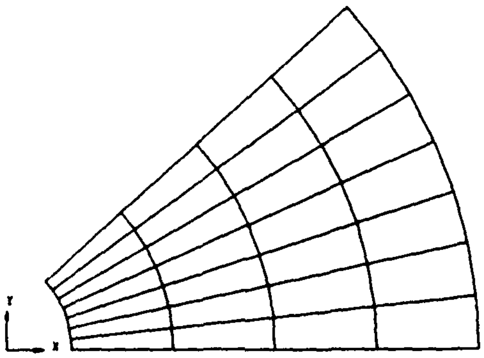

Figure 6-45. Annular section grid no. 3 (4 x 7)

in order to create a standing wave pattern in each basin. For each test, a tidal forcing amplitude of 1.0 ft and period of approximately 5 to 6 hr was selected.

169. Each simulation was run for 12 cycles (72 hr) with the time-step size and number of time-steps varying for each grid and Courant number. The model time step was selected such that Courant numbers of approximately 1, 4, and 8 could be maintained. Table 6-15 provides information for each of the numerical simulations. Initial flow field parameters were set equal to the values predicted by the analytic solution slightly after high tide when the velocities are small. The linear bottom friction coefficient was 6.0×10^{-6}.

Table 6-15

Annular Basin Simulations

Run	Grid	Δr (ft)	$\Delta r/L$	Δt (sec)	Number of Time-Steps	Courant Number	CPU Time (min)
1	20 x 14	4000	1/170	120	2160	0.9	12.87
2	20 x 14	4000	1/170	540	480	4.2	6.43
3	20 x 14	4000	1/170	1080	240	8.4	3.38
4	8 x 7	10000	1/70	300	864	0.9	2.55
5	8 x 7	10000	1/70	1350	192	4.2	0.70
6	8 x 7	10000	1/70	2700	96	8.4	0.43
7	4 x 7	20000	1/35	600	432	0.9	0.77
8	4 x 7	20000	1/35	2700	96	4.2	0.27
9	4 x 7	20000	1/35	5400	48	8.4	0.20

170. Figures 6-46 through 6-54 show the final two cycles (12 hr) of each simulation. Results of the test series show that simulations on the finer resolution (20 x 14) grid show good agreement with the exact solution for Courant numbers of 0.9, 4.2, and 8.4 (Figures 6-46 through 6-48). As the grids become coarser (8 x 7 and 4 x 7), the agreement between the model and exact solution diminishes (Figures 6-49 through 6-54). Similarly, as the Courant number increases, the agreement between the model and the exact solution diminishes.

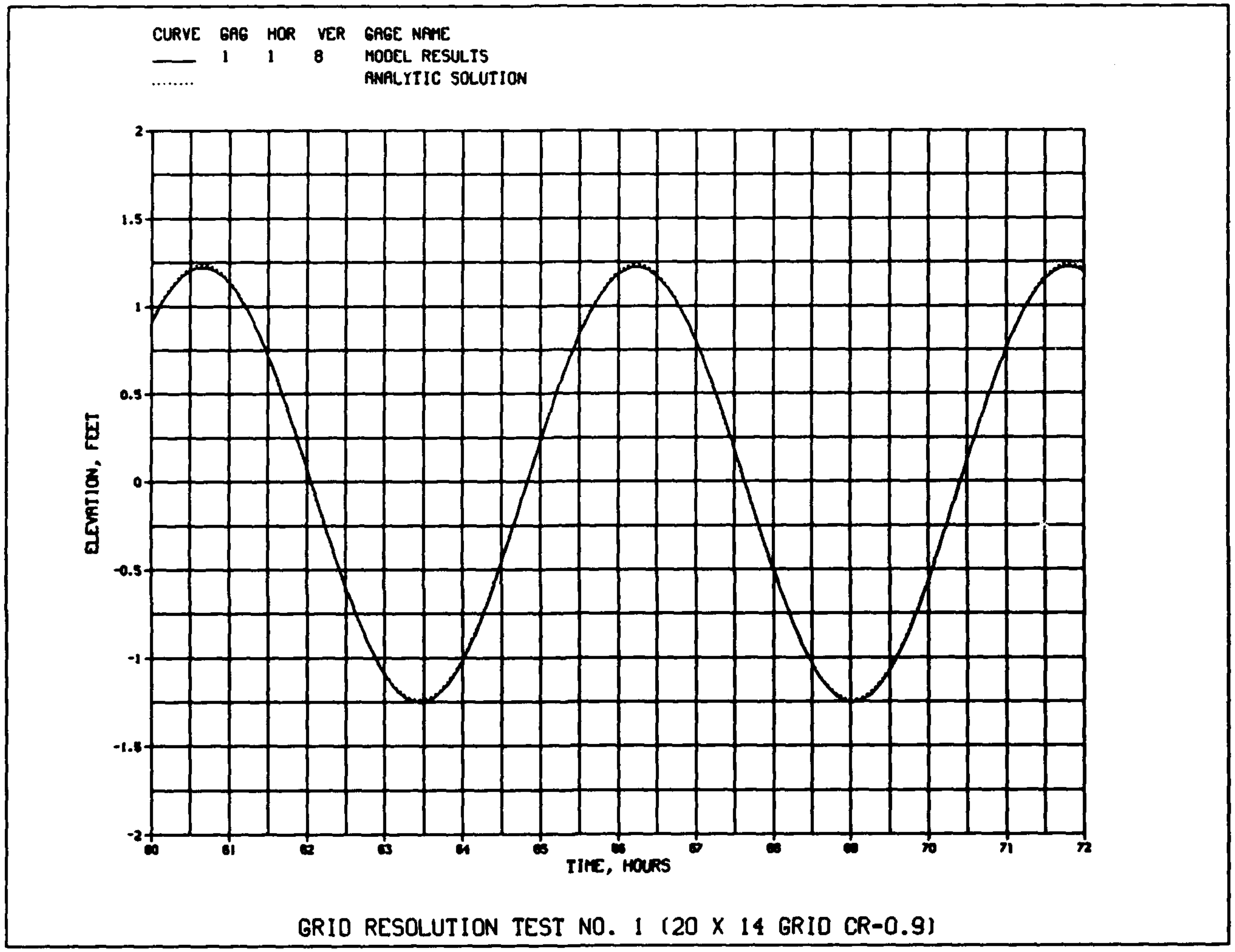

Figure 6-46. Grid resolution test 1: grid 1 (20 x 14) C_r = 0.9

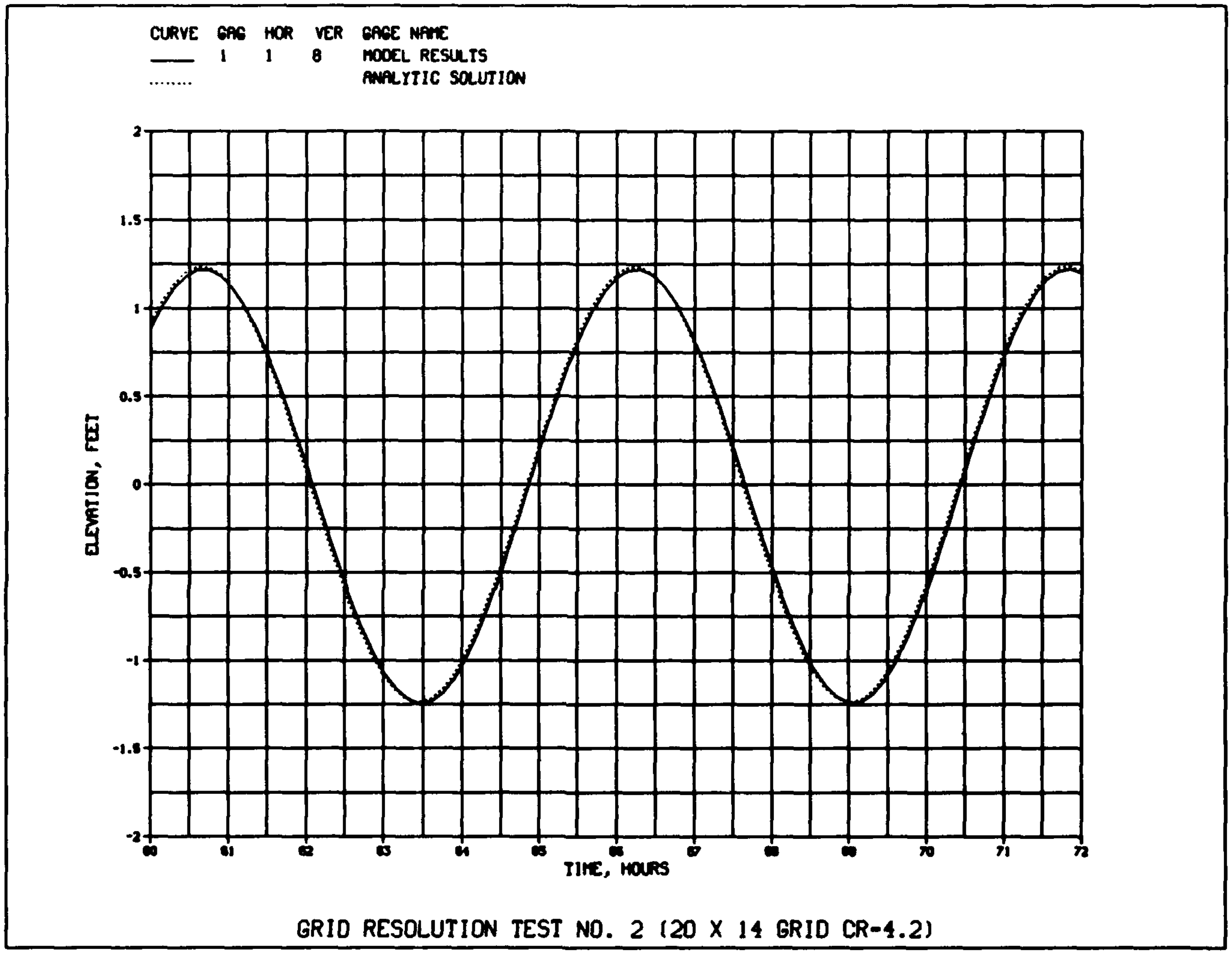

Figure 6-47. Grid resolution test 2: grid 1 (20 x 14) C_r = 4.2

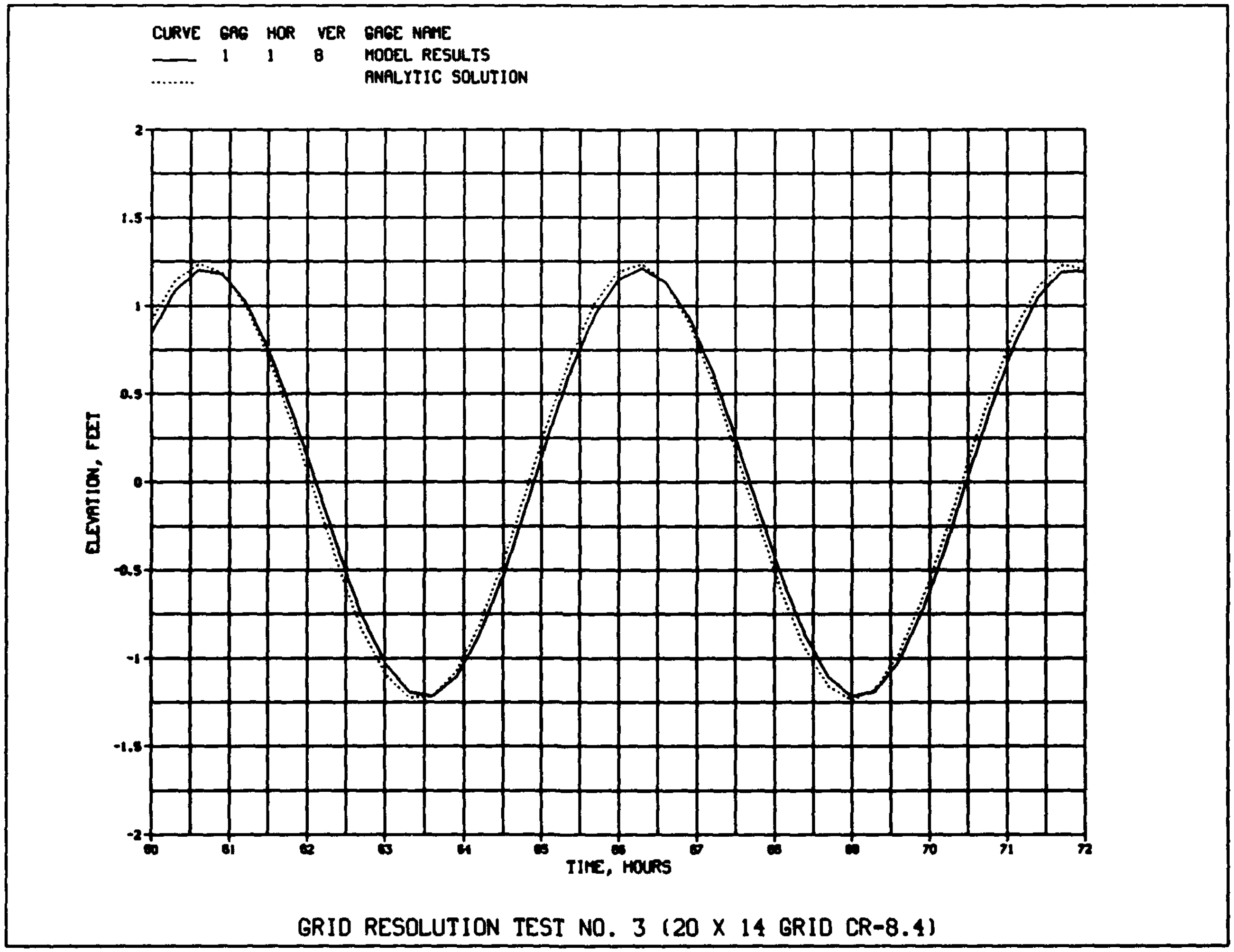

Figure 6-48. Grid resolution test 3: grid 1 (20 x 14) C_r = 8.4

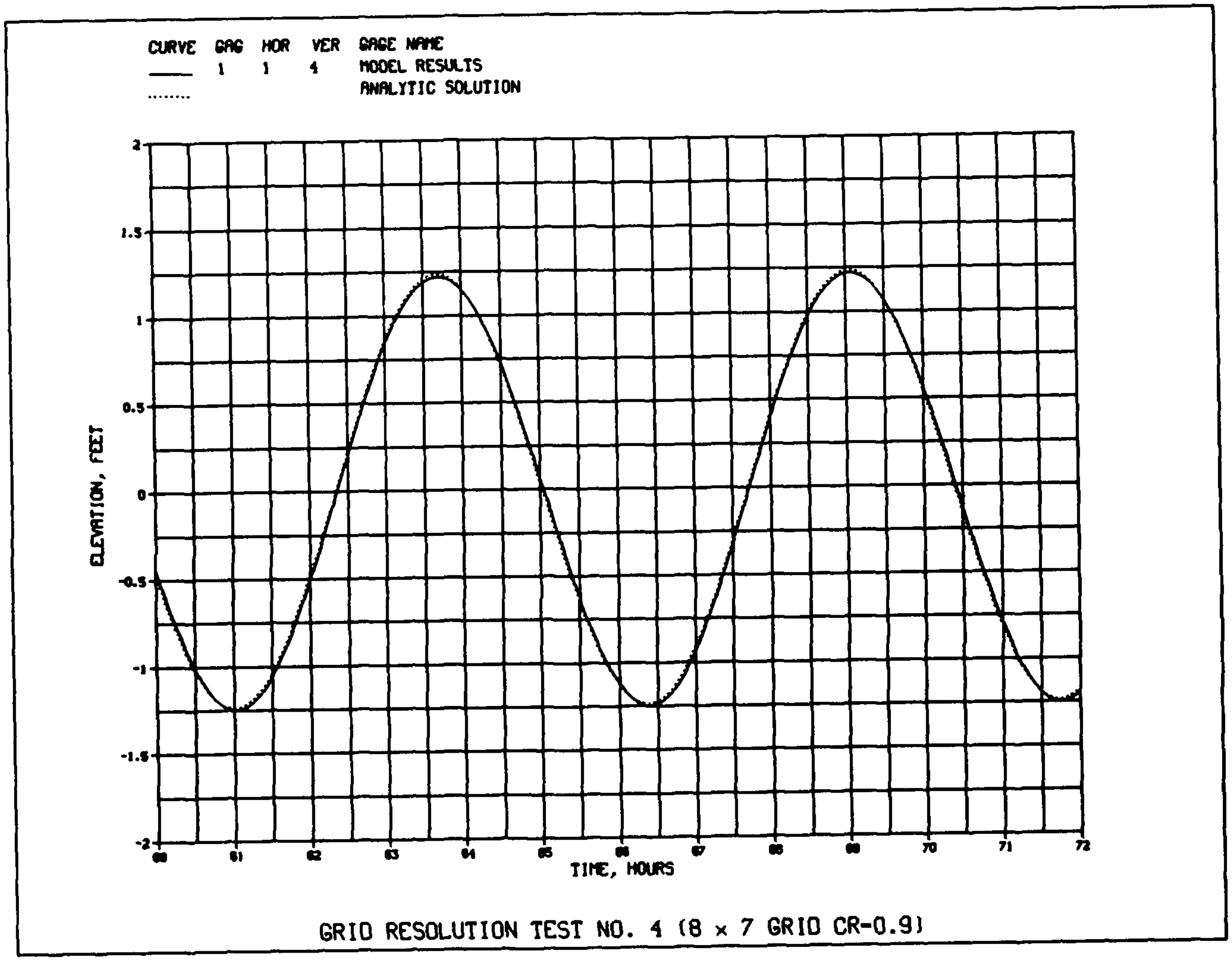

Figure 6-49. Grid resolution test 4: grid 2 (8 x 7) C_r = 0.9

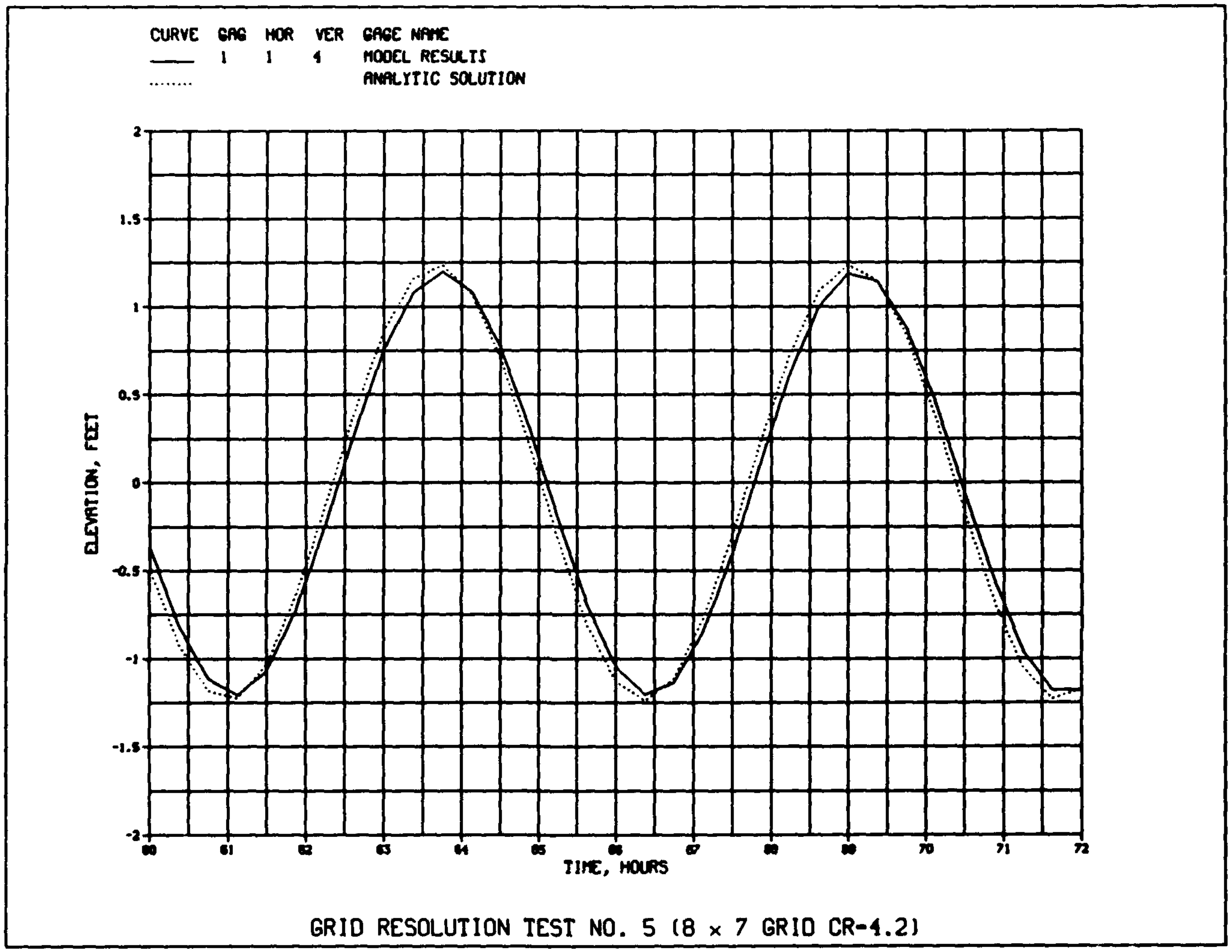

Figure 6-50. Grid resolution test 5: grid 2 (8 x 7) C_r = 4.2

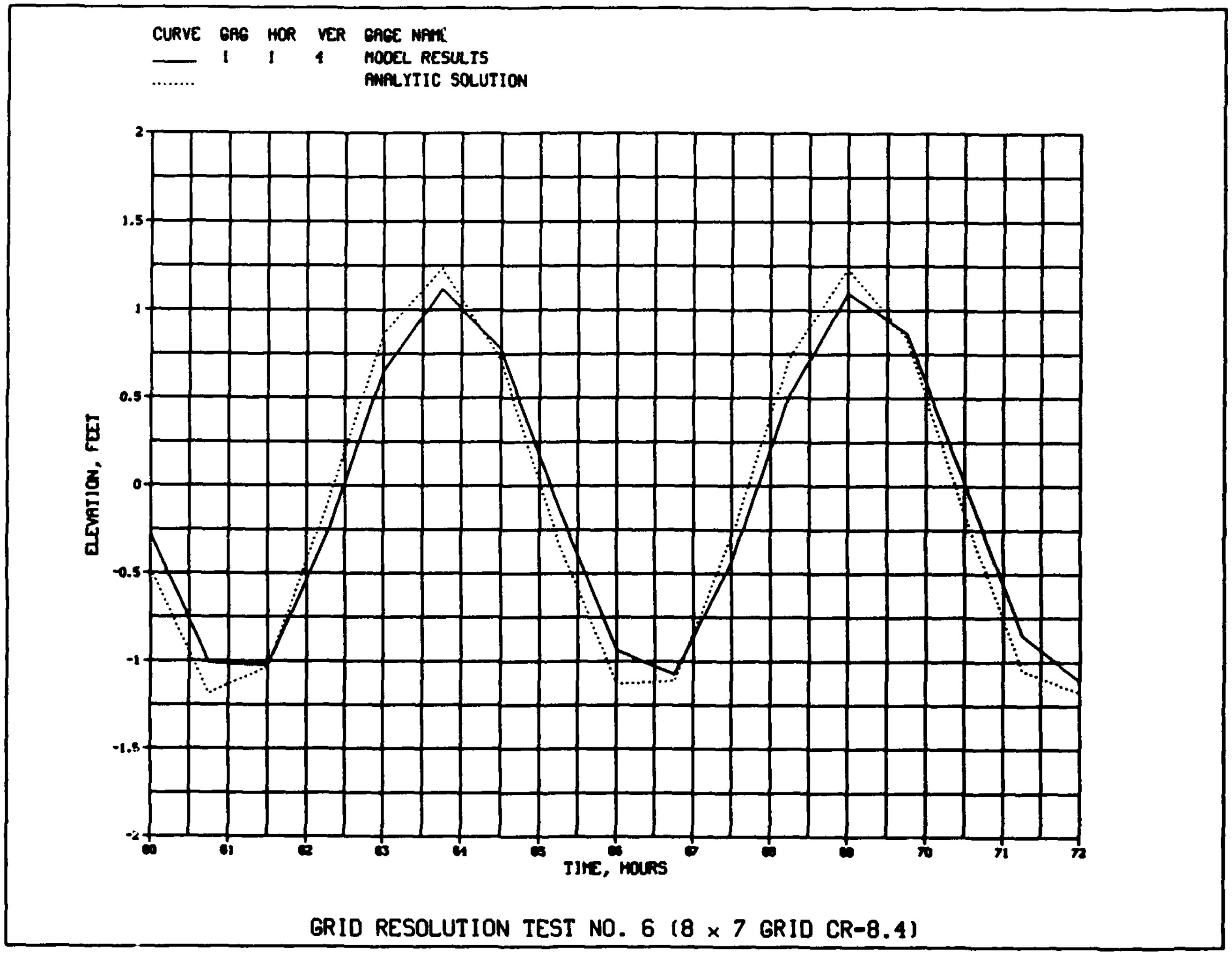

Figure 6-51. Grid resolution test 6: grid 2 (8 x 7) C_r = 8.4

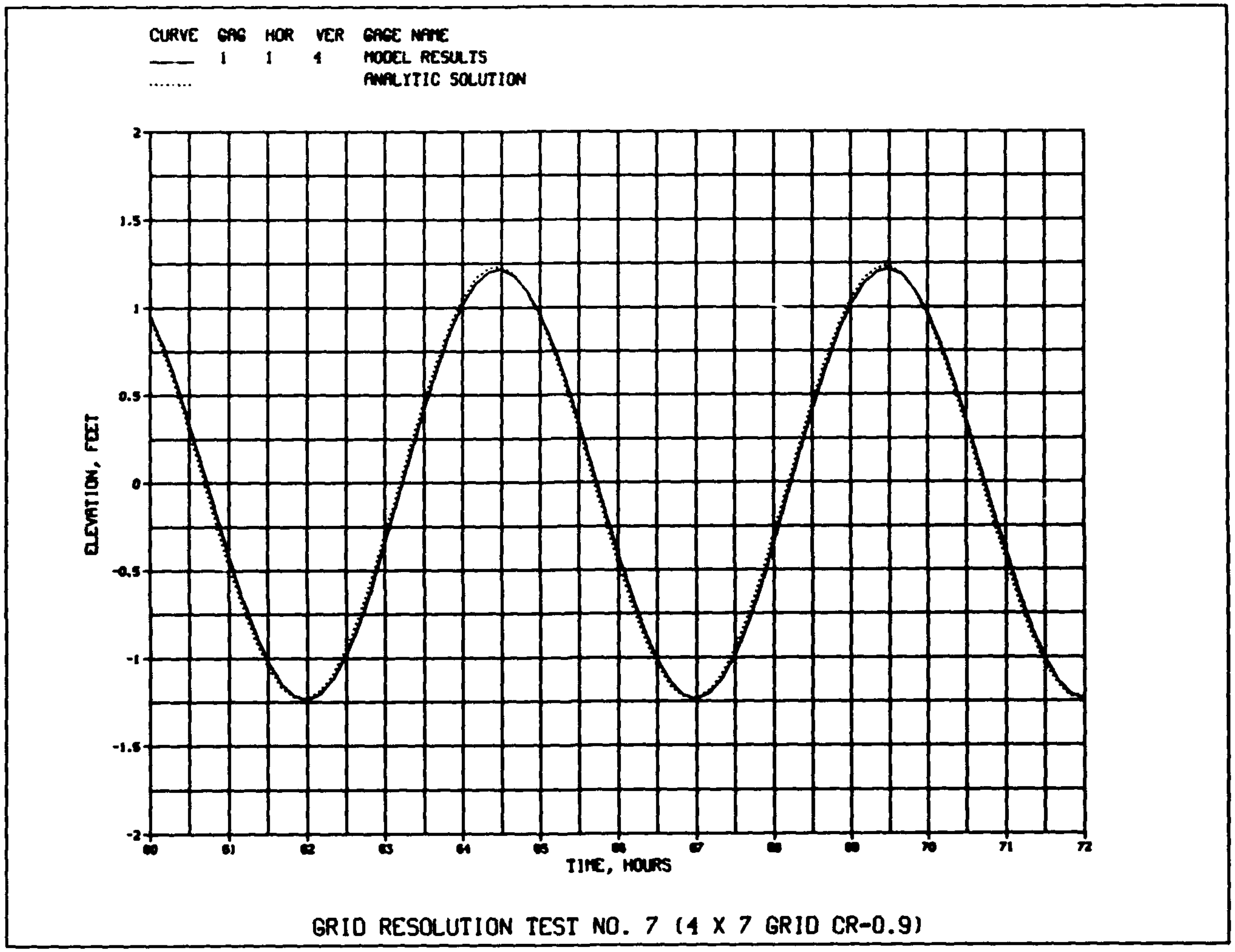

Figure 6-52. Grid resolution test 7: grid 3 (4 x 7) C_r = 0.9

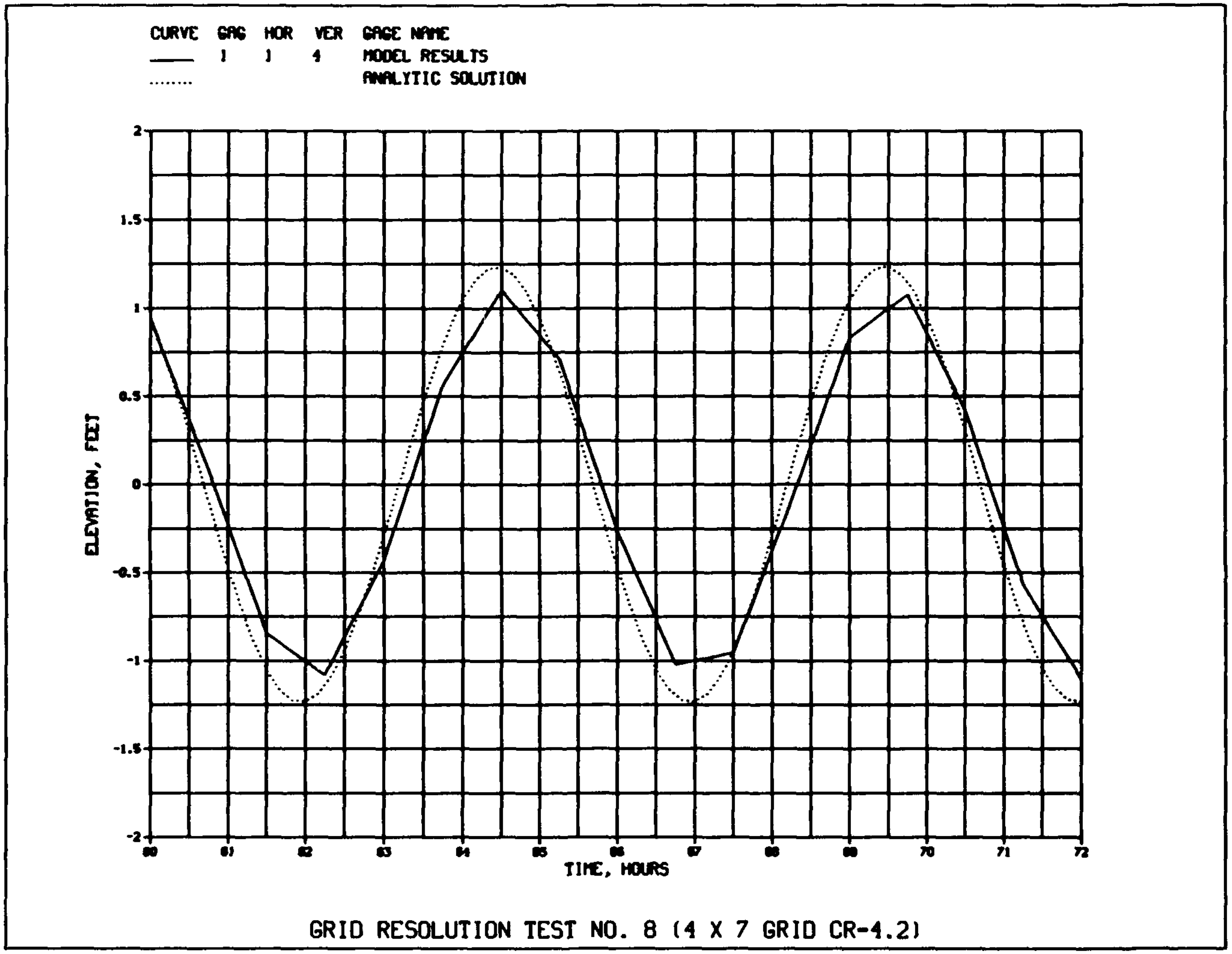

Figure 6-53. Grid resolution test 8: grid 3 (4 x 7) C_r = 4.2

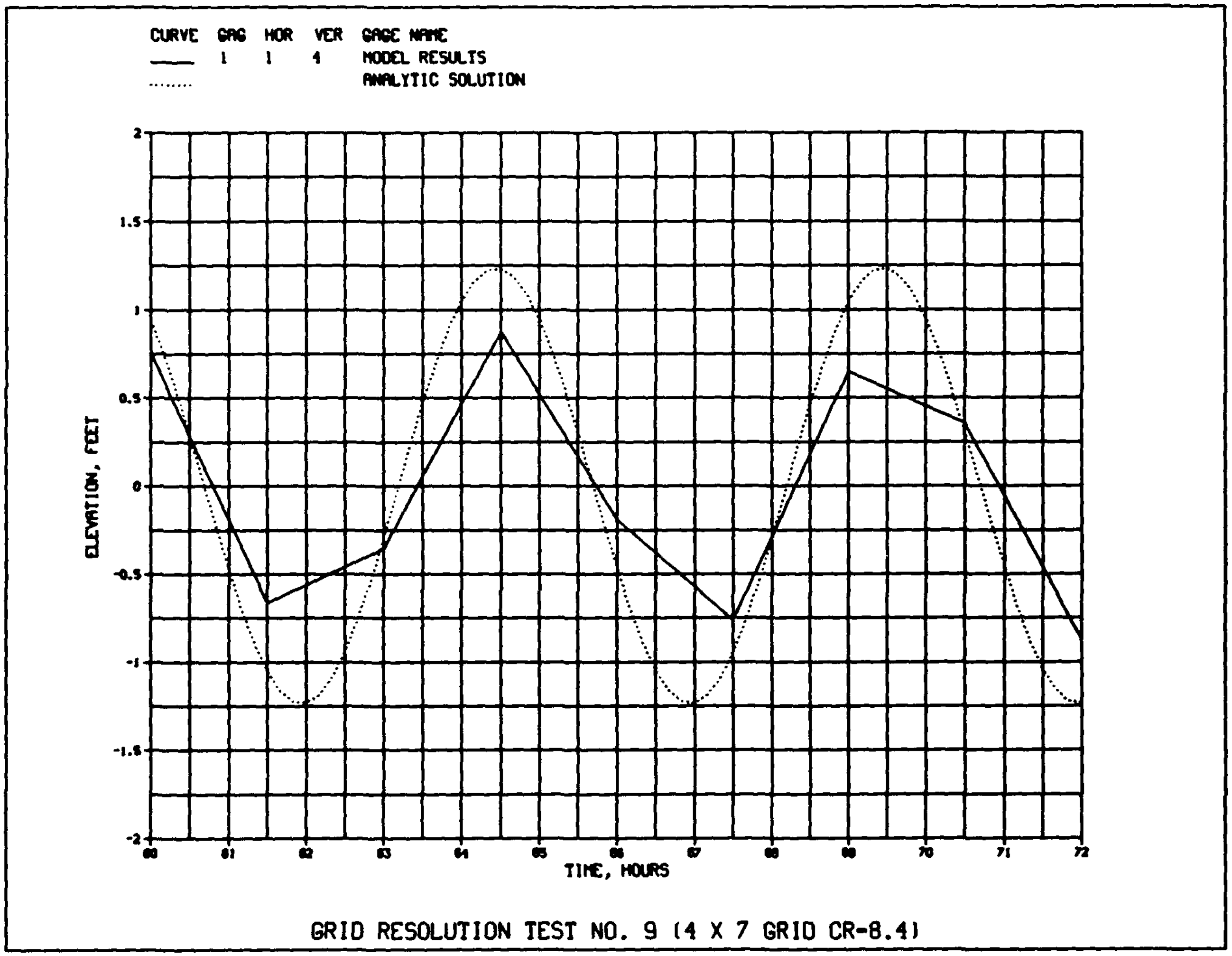

Figure 6-54. Grid resolution test 9: grid 3 (4 x 7) C_r = 8.4

171. The root-mean-square (RMS) error norm

$$RMS = \sqrt{\frac{\sum_{npts} (Exact\text{-}computed)^2}{npts}} \tag{6-48}$$

was used to measure the difference between the model and the exact solution for the entire simulation period (Table 6-16). The error increases as the grid becomes coarser (Δr increases) and as the Courant number increases (Δr increases).

172. The cost of the simulations, however, decrease as Δr and Δt increase. Table 6-15 shows the CPU time on a VAX 11/750 for each of the nine simulations. Grid 3 simulations took approximately 5 percent of the time of Grid 1 simulations.

173. The bias of the data:

$$Bias = \frac{\sum_{npts} (Exact\text{-}computed)}{npts} \tag{6-49}$$

shows that the model consistently underpredicted the exact solution (Table 6-17). This dampening is associated with a weighting factor of 1.0 used in these simulations.

Table 6-16

RMS Error Norms

	Grid No. 1 (20x14)		
	Courant No. 0.9	Courant No. 4.2	Courant No. 8.4
Gage 1	0.00889	0.02656	0.05086
2	0.00824	0.02469	0.04729
3	0.00626	0.01907	0.03660
4	0.00344	0.01065	0.02047
5	0.00003	0.00002	0.00002
	Grid No. 2 (8x7)		
	Courant No. 0.9	Courant No. 4.2	Courant No. 8.4
Gage 1	0.01431	0.05689	0.10481
2	0.01360	0.05412	0.09977
3	0.01062	0.04239	0.07830
4	0.00593	0.02391	0.04434
5	0.00002	0.00001	0.00001
	Grid No. 3 (4x7)		
	Courant No. 0.9	Courant No. 4.2	Courant No. 8.4
Gage 1	0.02220	0.08822	0.13989
2	0.01775	0.07087	0.11280
3	0.01014	0.04074	0.06524
4	0.0002	0.00001	0.00001

Table 6-17

Bias

Grid No. 1 (20x14)

	Courant No. 0.9	Courant No. 4.2	Courant No. 8.4
Gage 1	0.00364	0.00377	0.00392
2	0.00702	0.00725	0.00756
3	0.00959	0.00995	0.01033
4	0.01101	0.01144	0.01186
5	0.01101	0.01144	0.01186

Grid No. 2 (8x7)

	Courant No. 0.9	Courant No. 4.2	Courant No. 8.4
Gage 1	0.00337	0.00361	0.00386
2	0.00658	0.00707	0.00742
3	0.00907	0.00973	0.01025
4	0.01041	0.01121	0.01180
5	0.01041	0.01121	0.01180

Grid No. 3 (4x7)

	Courant No. 0.9	Courant No. 4.2	Courant No. 8.4
Gage 1	0.00292	0.00315	0.00336
2	0.00521	0.00571	0.00608
3	0.00649	0.00714	0.00767
4	0.00649	0.00714	0.00767

174. The final example using the CLHYD model is a field application at Indian River Inlet, Delaware (Figure 6-55). The purpose of this example is to demonstrate CLHYD's ability in a more realistic (field) environment. Indian River Inlet was selected for this demonstration because field data and results from the WES Implicit Flooding Model (WIFM) exist at this location.

175. Tide and velocity gage data were collected at Indian River Inlet during the period 29 June 1988 to 1 July 1988. Tide gage and velocity station locations are shown in Figures 6-55 and 6-56, respectively. WIFM was applied at Indian River Inlet and vicinity using the 1988 prototype gage data for calibration purposes (Lillycrop et al., in preparation). These data were used for comparison to CLHYD.

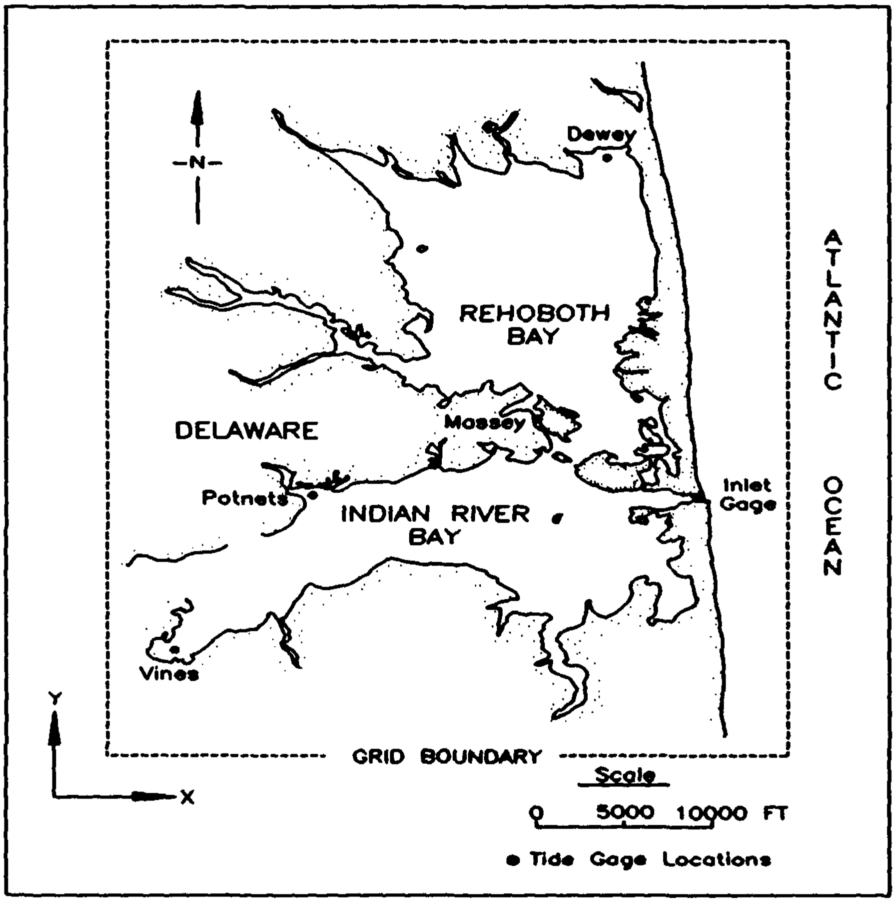

Figure 6-55. Indian River Inlet and vicinity

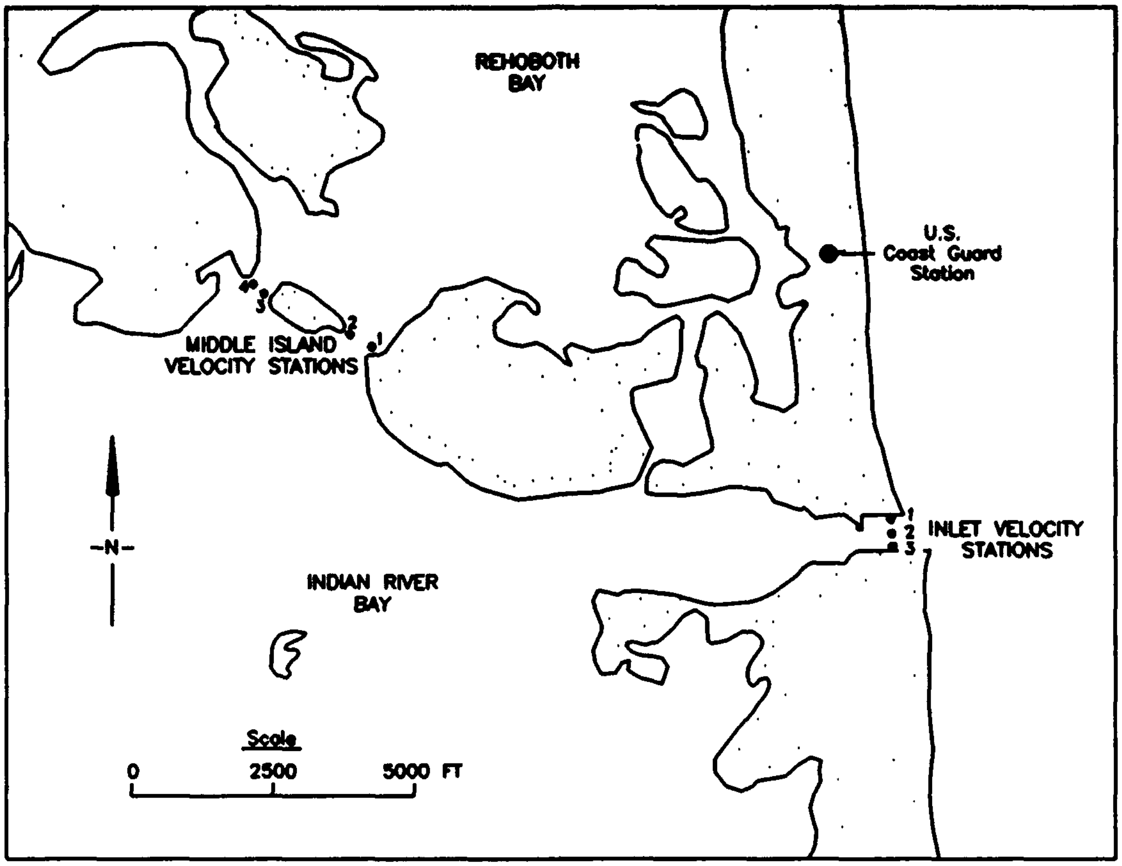

Figure 6-56. Velocity station locations

176. A portion of the input data set for the CLHYD application is given in Appendix 6-C. The grid boundaries are shown in Figure 6-55. In this application, an 84 x 84 cell variable rectilinear grid was used to represent the approximately 66,666 x 56,666 ft study area. This information is specified on the GRIDSPEC record as variable ICELLS=84, variable JCELLS=84, variable ALXREF=66666, and variable ALYREF=56666. The units of the grid data (GUNITS) were specified as ENGLISH, which means the length scale used for the grid was feet. The grid coordinates were provided from the WIFM simulation as "grid corner" points; therefore, a GRIDCORN record and a double matrix of grid coordinates followed the GRIDSPEC record. The matrix of x-values for each corner point (XCT) is read into the model followed by the matrix of y-values for each corner point (YCT). The reader should refer to the GRIDCORN record in Appendix 6-B for details.

177. The simulation period was 63 hr (11,340 time-steps) with the first 37 hr representing the model warm-up period. The time-step (DELT) was 20 sec. Gage data (free surface elevations and water velocities) were recorded every 90 time-steps (30 min) as specified by variable NFREQ on the TIMESPEC record. This information was used to produce time-histories of CLHYD model results at the prototype tide and velocity gage locations. Non-linear (advection) terms were also included in the governing equations for this simulation (ADDTERMS record). The coriolis coefficient (COR) was set to 0.00009 on record ADDTERMS.

178. The offshore and lateral boundaries were forced with prototype tide data, and the interior (bay) boundary was assumed to be a closed boundary. The prototype tide data were provided as tabular elevation values at 30-min intervals (1,800 sec). This information was represented in the model using an XBOUNDRY record, two YBOUNDRY records, a FUNCTION record, and a TERECORD record followed by the actual elevation values that forced the offshore and lateral boundaries (see Appendix 6-C).

179. Hourly wind data (Figure 6-57) were obtained from the U.S. Coast Guard Station located approximately 1 mile north of the inlet (Figure 6-56). The temporally varying prototype wind data were applied at each grid point, which indicates that wind was assumed to be spatially constant in the model (WNTRVL=TVRUNISP). From the prototype data, a series of TABWINDS records was constructed to represent the temporally varying, spatially constant wind field for the time period of the simulation.

180. The bathymetric data used for the CLHYD simulation were identical to the bathymetric data used for the WIFM application. Bathymetric data are included in the CLHYD model using a BATHSPEC record followed by a matrix of depth values for each grid cell. The depth values relative to the National Geodetic Vertical Datum (NGVD) were obtained for this application from the National Oceanic and Atmospheric Administration (NOAA) chart 12216. The units of the bathymetric data (BUNITS) are feet. The matrix of depth values was read in the longshore direction (increasing Y), then moving offshore (increasing X). This corresponds to a BSEQ value of YX.

181. In the WIFM application, the jetties were represented by designating "land" cells at the jetty locations rather than using XBARRIER and YBARRIER records. The narrow cell width (approximately 130 ft) in the

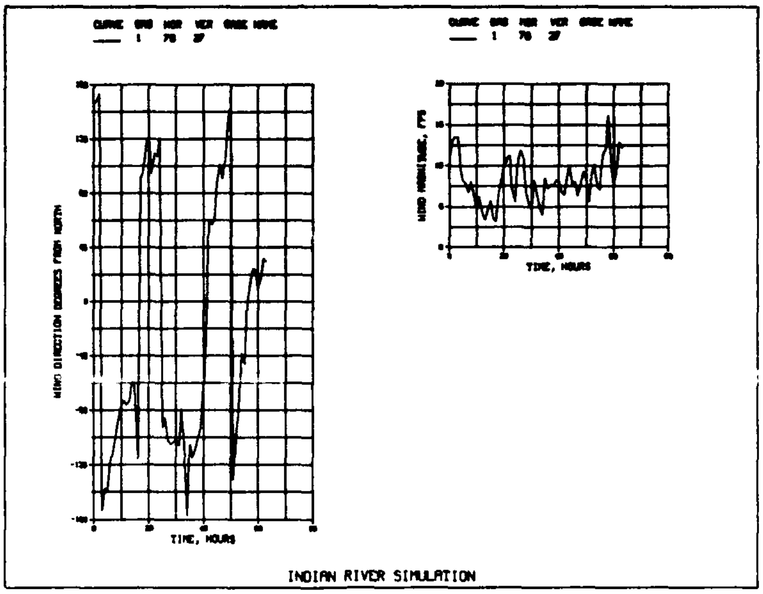

Figure 6-57. Wind data used in Indian River application

vicinity of the inlet justified the use of land designation rather than infinitely thin barriers.

182. In the WIFM application, large friction values were selected for the cells near the inlet entrance to account for the large hydraulic loss that occurs there. For comparison purposes, the friction values used to obtain the best calibration of the WIFM model were used in the CLHYD model. Friction values were thus provided for each individual cell by selecting "FRICTION TABULAR" followed by a matrix of Manning's *n* values representing the friction in each grid cell (see Appendix 6-C).

183. Time-history (gage) data were recorded at the five tide gage locations and at the seven velocity station locations using RECGAGE records. The free surface elevation and the u- and v-velocity components were recorded every 90 time-steps (variable NFREQ=90 on the TIMESPEC record) for each gage location. Using a RECSNAPS record, snapshots of the entire flow field were recorded every 4 hr (720 time-steps), beginning at hour 44 (time-step 7,920) and ending at hour 52 (time-step 9,360).

184. A comparison of CLHYD model results to WIFM results and prototype data are given for the five tide gage locations for the final 23 hr of the simulation (Figures 6-58 through 6-62). The agreement between model results and prototype data is excellent for all five gages.

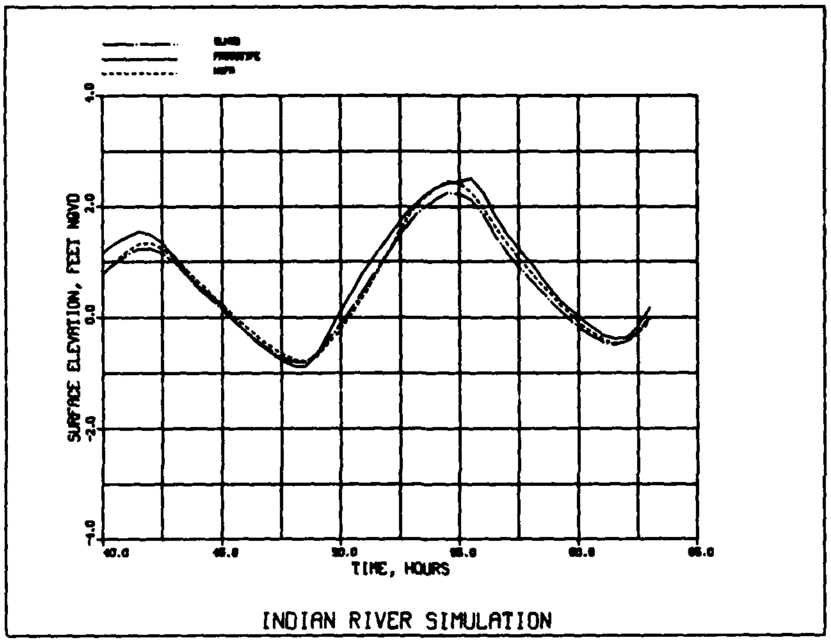

Figure 6-58. Comparison of water surface elevations at Vines gage

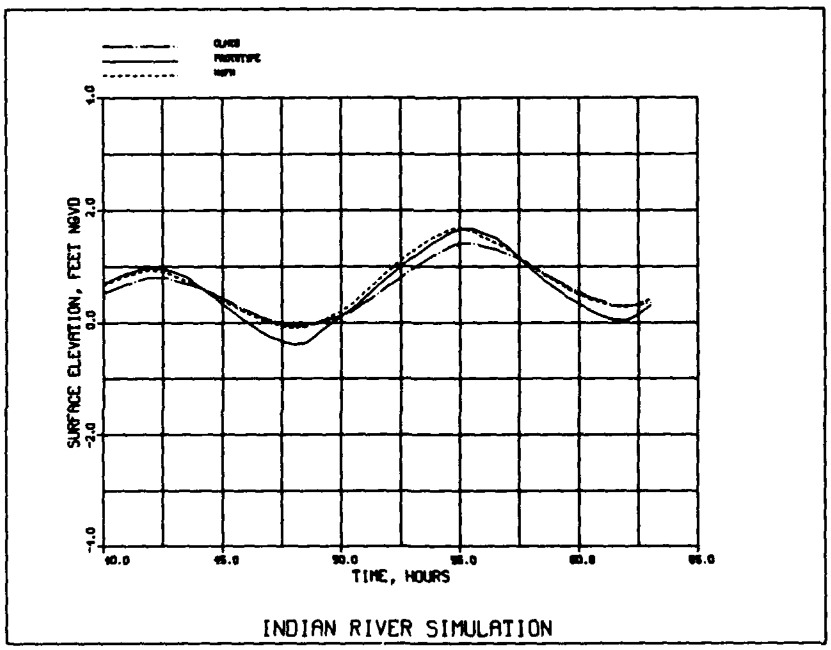

Figure 6-59. Comparison of water surface elevations at Massey gage

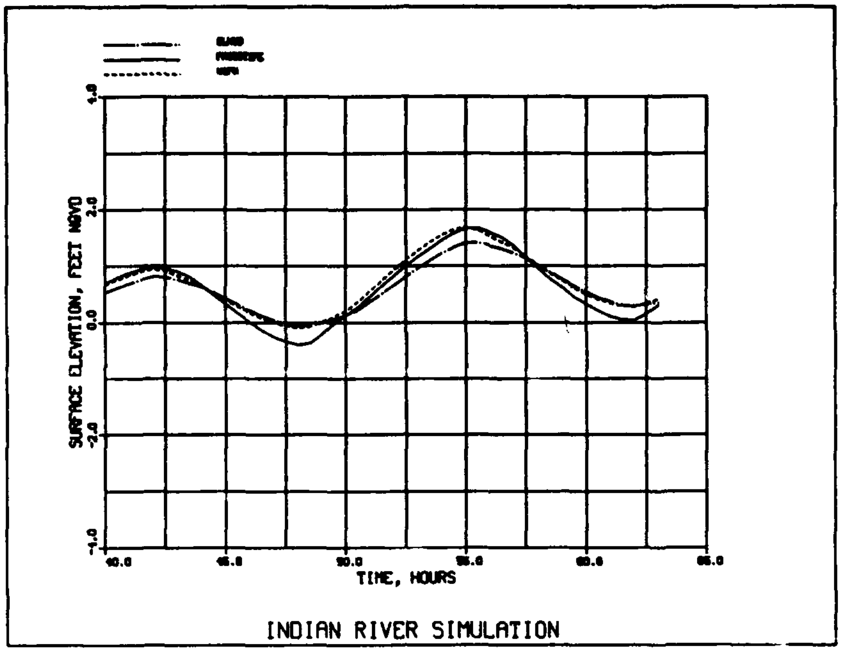

Figure 6-60. Comparison of water surface elevations at Massey gage

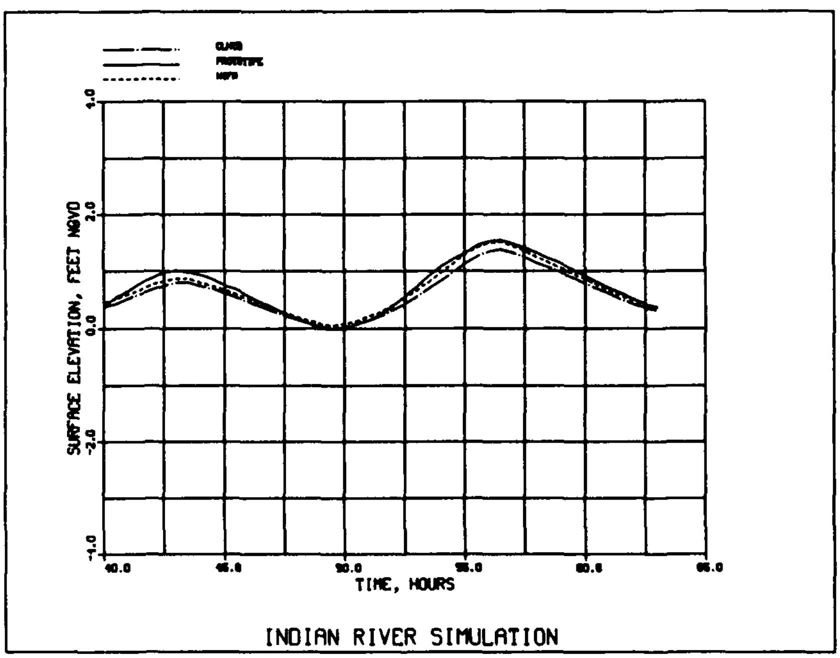

Figure 6-61. Comparison of water surface elevations at Dewey gage

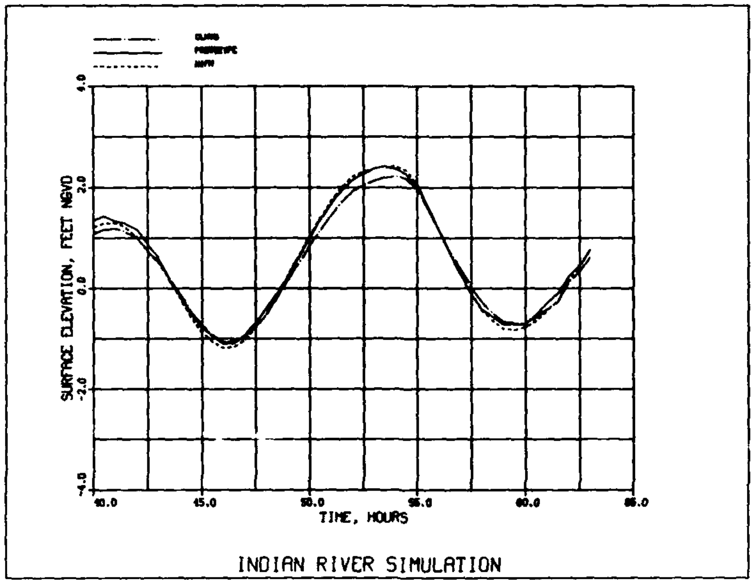

Figure 6-61. Comparison of water surface elevations at Inlet gage

185. Similarly, a comparison of CLHYD model results to WIFM results and prototype data for the seven velocity stations is given in Figures 6-63 through 6-69 for the final 23 hr of the simulation. Some of the WIFM velocity results were given as averaged velocities between adjacent grid cells (Inlet Stations 1 and 3 and Middle Island Station 1). This procedure was repeated with CLHYD results to obtain a consistent comparison. In analyzing the results, it is found that the agreement at the Inlet Stations is good for stations 1 and 2, but the model underpredicts the magnitude of the velocities appreciably at Inlet Station 3 (Figure 6-65). Several factors may account for the discrepancies in the velocities. First, gage locations are approximated using a 200- to 500-ft grid cell, and therefore the exact location of the actual gage is only approximated. Secondly, friction was adjusted in the WIFM model to simulate the hydraulic loss through the inlet and obtain the best agreement between WIFM model results and measured velocities. The friction values used in CLHYD could have been altered to improve the agreement; however, such a rigorous calibration is not the primary focus for this simple example. The agreement between the CLHYD model results and the prototype at the Middle Island Stations is excellent for station 1, good for stations 2 and 4, but again, the model underpredicts the magnitude of the velocity at station 3.

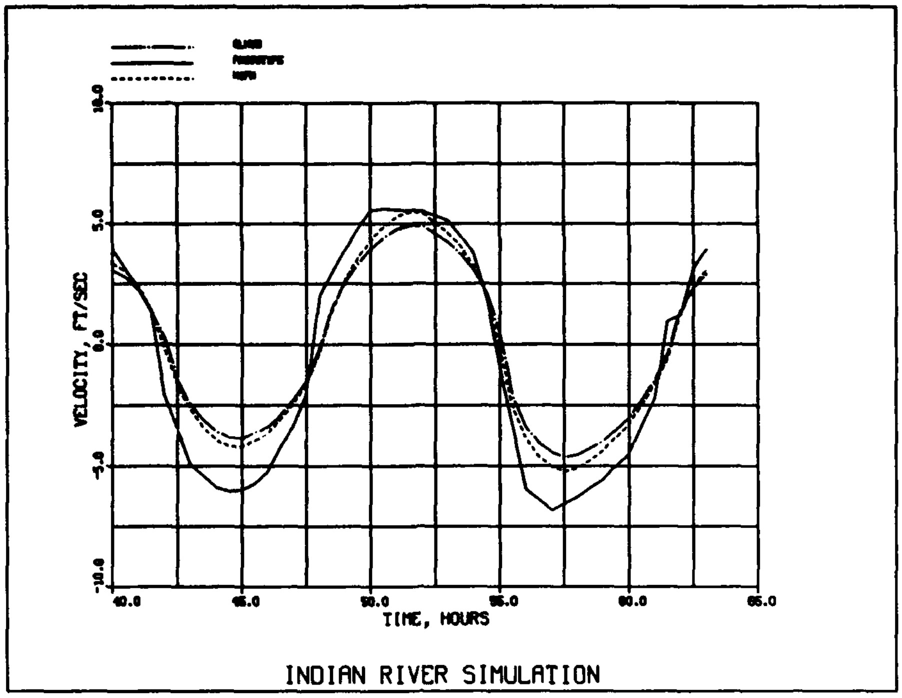

Figure 6-63. Comparison of water surface elevations at Inlet gage

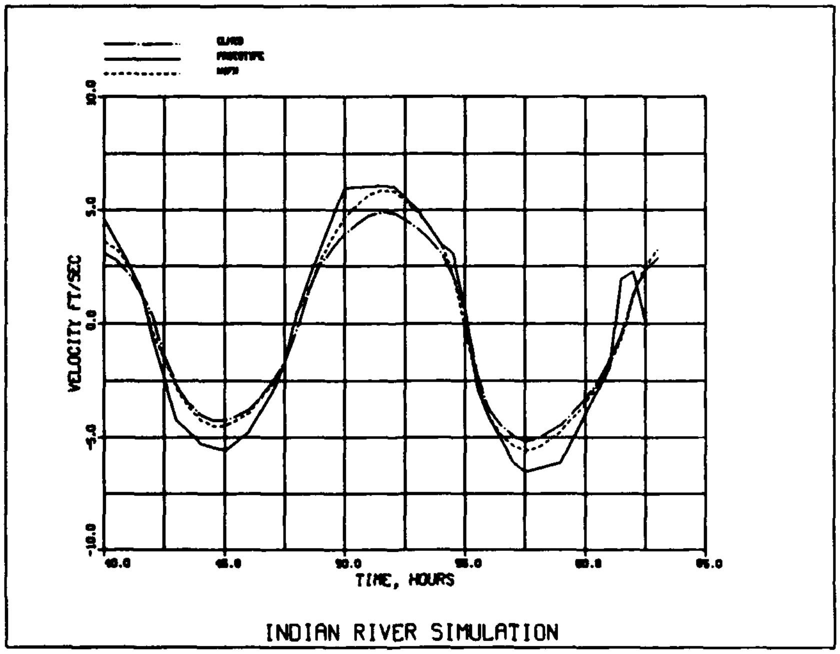

Figure 6-64. Comparison of velocities at Inlet Station 1

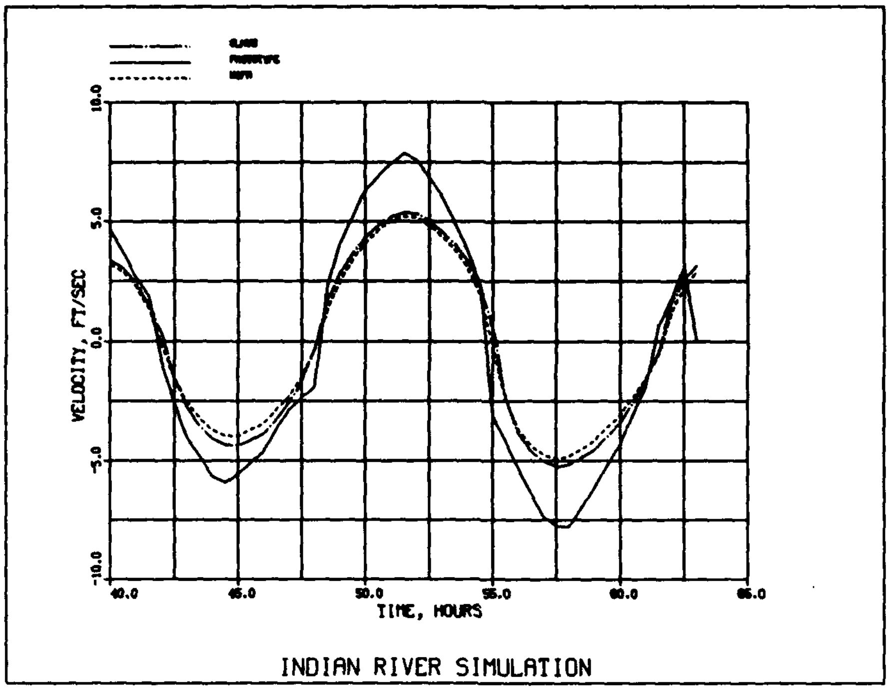

Figure 6-65. Comparison of velocities at Inlet Station 2

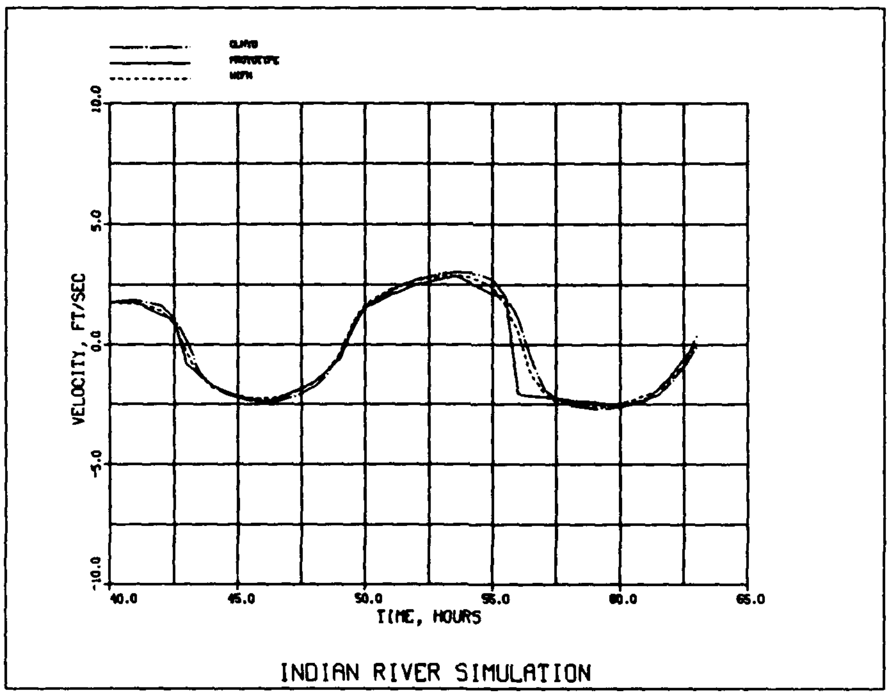

Figure 6-66. Comparison of velocities in Inlet Station 3

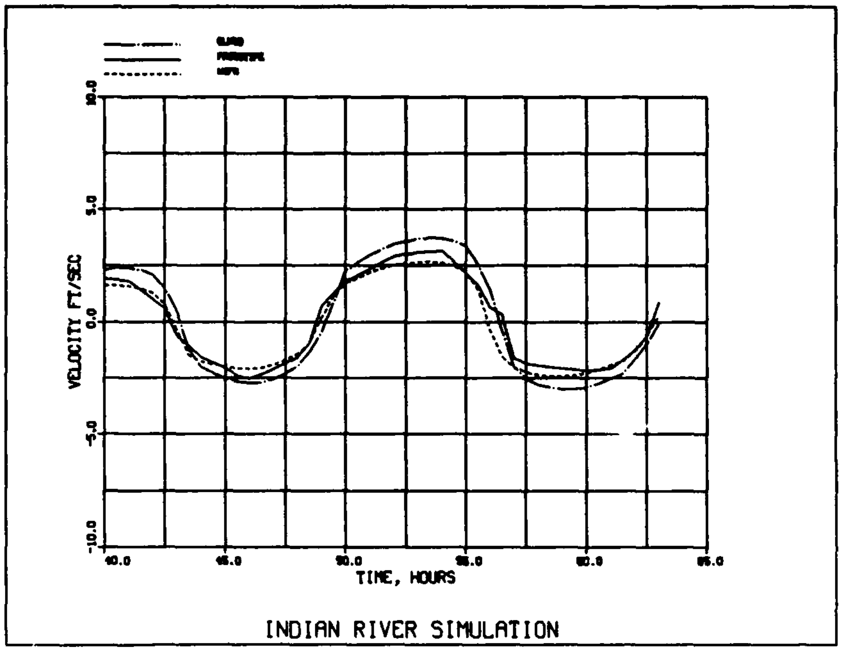

Figure 6-67. Comparison of velocities at Middle Island Station 1

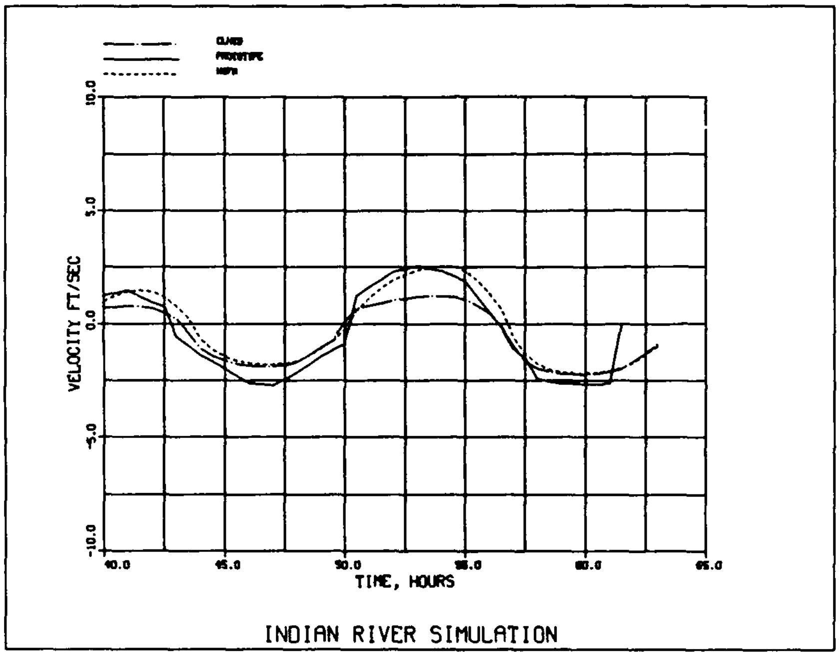

Figure 6-68. Comparison of velocities at Middle Island Station 2

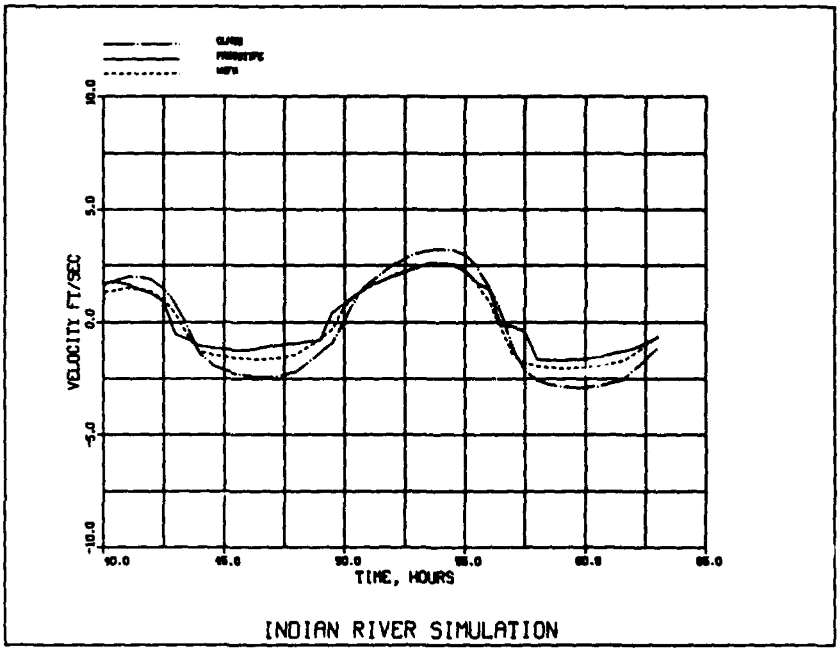

Figure 6-69. Comparison of velocities at
Middle Island Station 3

186. Discharge ranges were selected across the inlet and the entrance to Rehobeth Bay. This was specified in the model by including two RECRANG records in the input data set to record flow rates for the entire simulation period at these two locations (Figures 6-70 and 6-71). This information can then be used to compute the tidal prism. The flow rate through the inlet is approximately 12,000 cfs, whereas the unit flow rate into Rehobeth Bay is only 7,000 cfs.

187. Snapshots of the entire flow field were recorded at hours 44, 48, and 52. The peak ebb (hour 44) and peak flood (hour 52) snapshots are shown in Figures 6-72 and 6-73, respectively. Velocities are greatest through the inlet throat as expected. Velocity vectors for every eighth cell were plotted in the figures.

188. This field application is intended to illustrate to the user the various capabilities of the CLHYD model. The complexity of "real-world" problems makes the application of models such as CLHYD a suitable means of reaching an engineering decision to a specific coastal problem.

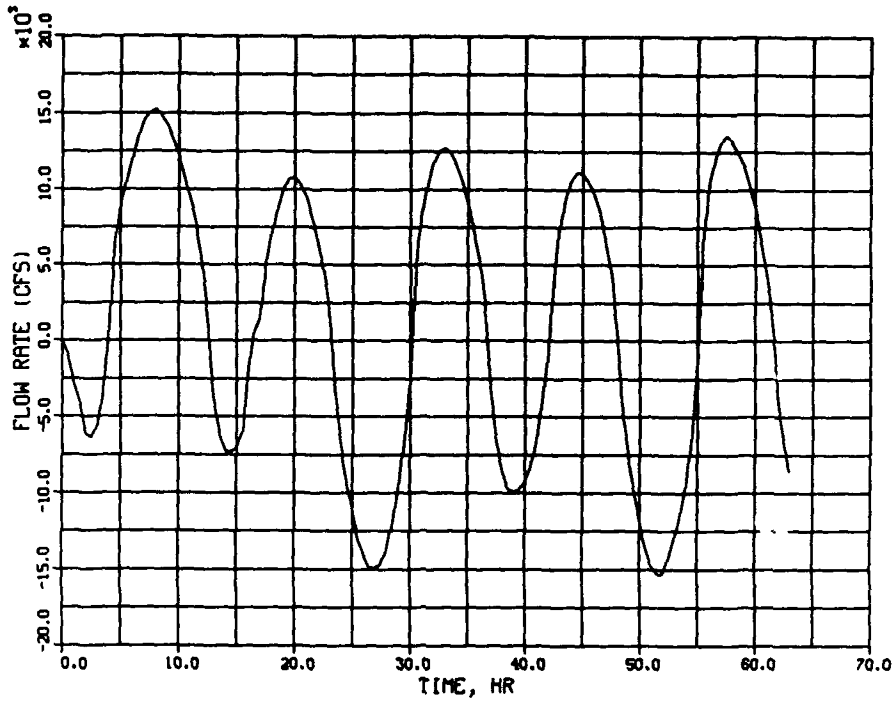

Figure 6-70. Discharge through Indian River Inlet

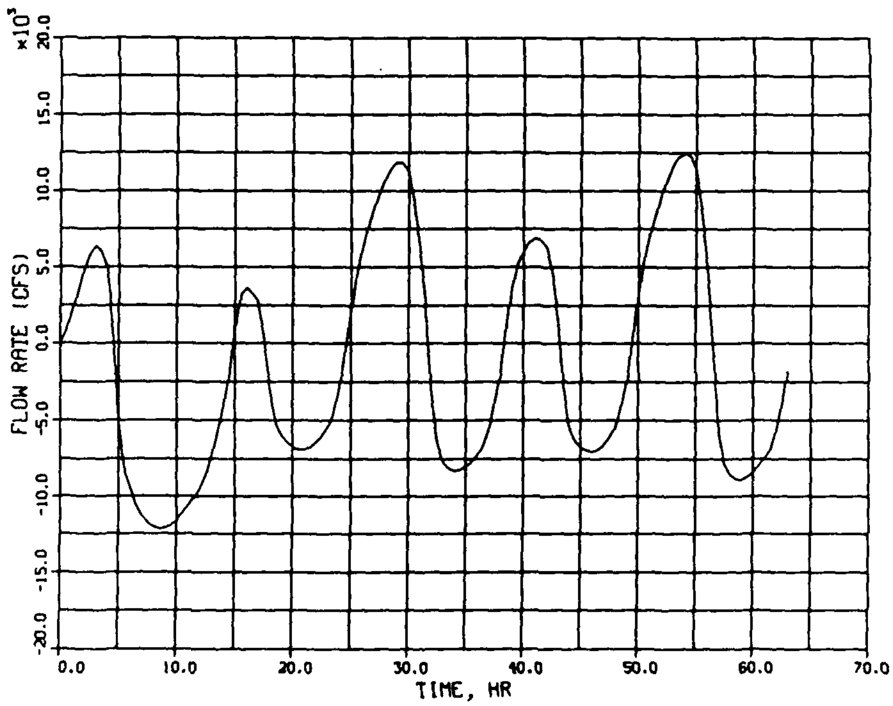

Figure 6-71. Discharge into Rehobeth Bay

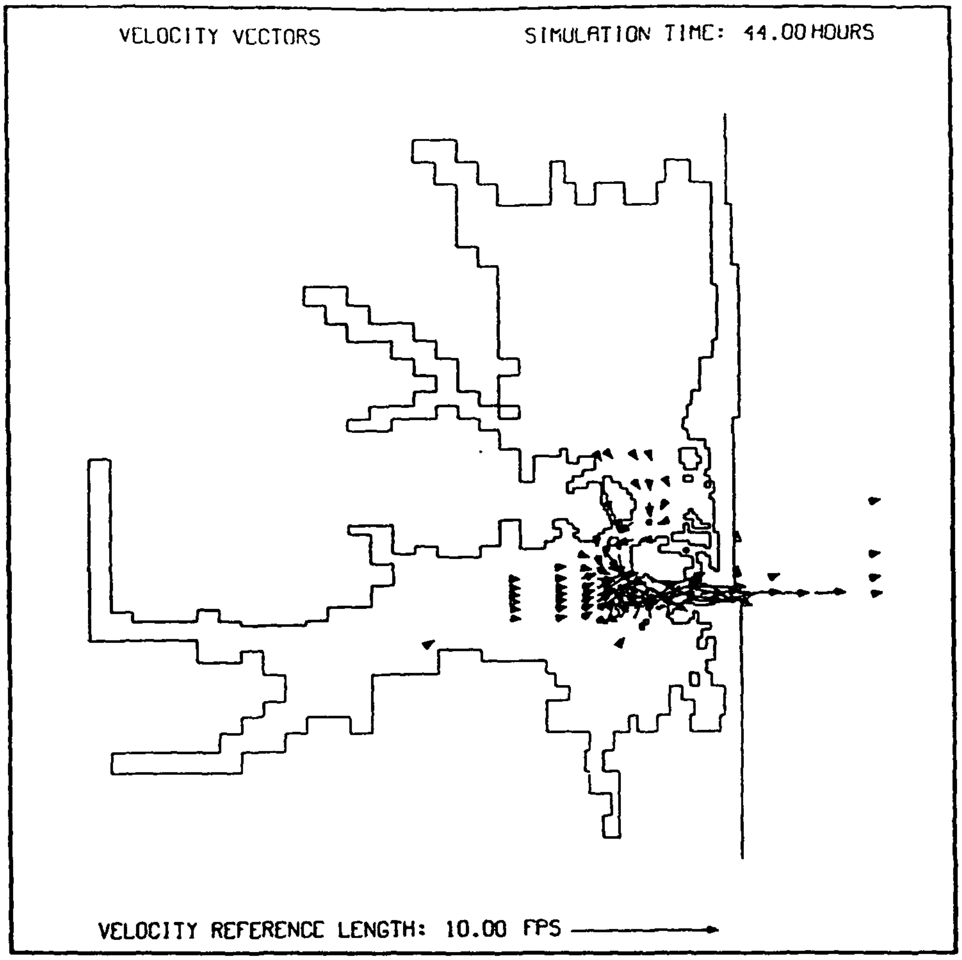

Figure 6-72. Snapshot at hour 44

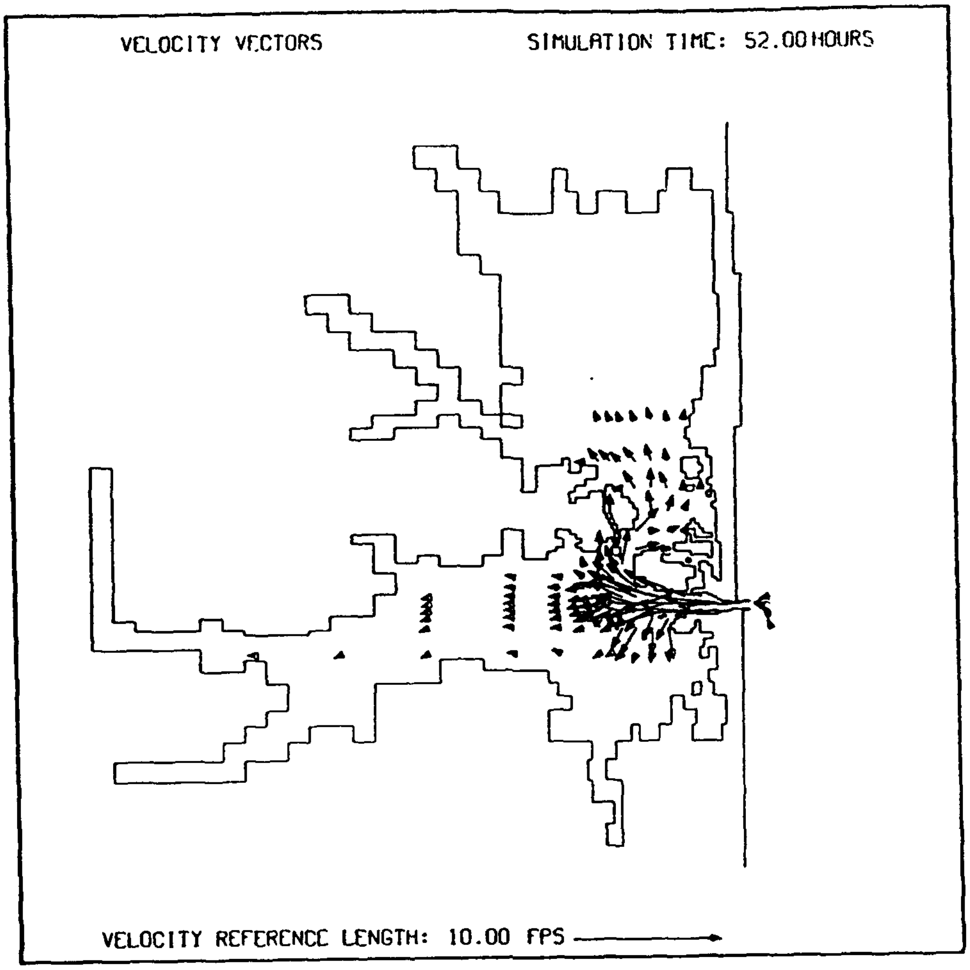

Figure 6-73. Snapshot at hour 52

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APPENDIX 6-A: TRANSFORMATION OF ADVECTION AND DISPERSION TERMS

The advective (inertia) terms in the x- and y-momentum equations are given as:

X-Momentum

$$\frac{\partial}{\partial x}\left(\frac{UU}{H}\right) + \frac{\partial}{\partial y}\left(\frac{UV}{H}\right)$$

Y-Momentum

$$\frac{\partial}{\partial x}\left(\frac{UV}{H}\right) + \frac{\partial}{\partial y}\left(\frac{VV}{H}\right)$$

These expressions are represented in the transformed plane as:

X-Momentum

$$\frac{-\frac{\partial x}{\partial \eta}}{g_u H}\left[U\frac{\partial}{\partial \xi}\left(\frac{U}{H}\frac{\partial y}{\partial \xi} + \frac{V}{H}\frac{\partial y}{\partial \eta}\right)\sqrt{g_s} + V\frac{\partial}{\partial \eta}\left(\frac{U}{H}\frac{\partial y}{\partial \xi} + \frac{V}{H}\frac{\partial y}{\partial \eta}\right)\sqrt{g_v}\right]$$

$$+ \frac{\frac{\partial y}{\partial \eta}}{g_u H}\left[U\frac{\partial}{\partial \xi}\left(\frac{U}{H}\frac{\partial x}{\partial \xi} + \frac{V}{H}\frac{\partial x}{\partial \eta}\right)\sqrt{g_s} + V\frac{\partial}{\partial \eta}\left(\frac{U}{H}\frac{\partial x}{\partial \xi} + \frac{V}{H}\frac{\partial x}{\partial \eta}\right)\sqrt{g_v}\right]$$

Y-Momentum

$$\frac{\frac{\partial x}{\partial \xi}}{g_v H}\left[U\frac{\partial}{\partial \xi}\left(\frac{U}{H}\frac{\partial y}{\partial \xi} + \frac{V}{H}\frac{\partial y}{\partial \eta}\right)\sqrt{g_u} + V\frac{\partial}{\partial \eta}\left(\frac{U}{H}\frac{\partial y}{\partial \xi} + \frac{V}{H}\frac{\partial y}{\partial \eta}\right)\sqrt{g_s}\right]$$

$$- \frac{\frac{\partial y}{\partial \xi}}{g_v H}\left[U\frac{\partial}{\partial \xi}\left(\frac{U}{H}\frac{\partial x}{\partial \xi} + \frac{V}{H}\frac{\partial x}{\partial \eta}\right)\sqrt{g_u} + V\frac{\partial}{\partial \eta}\left(\frac{U}{H}\frac{\partial x}{\partial \xi} + \frac{V}{H}\frac{\partial x}{\partial \eta}\right)\sqrt{g_s}\right]$$

Finite Difference Representation

The upwind treatment of the advective terms, otherwise known as the "pigpen method" (Roache 1972), is implemented in the CLHYD model. In this formulation, the effect of a perturbation is carried only in the direction of

the velocity. D. B. Spalding called this the pigpen method because a concentrated quantity would be "smelled" only downwind of the source. This translates into the model as meaning that a point in the grid is affected only by what occurs upwind of it. The advantages of this method is its simplicity in formulation and stability of the solution due to its dispersive nature. The stability can also act as a disadvantage if the dispersion becomes excessive.

X-Momentum

For flow in the positive x-direction, the finite differences are taken between cells *i-1* and *i* in accordance with the pigpen method:

$$\frac{-\frac{\partial x}{\partial \eta}}{g_s H}\left[\frac{U\left(\frac{U}{H}\frac{\partial y}{\partial \xi}+\frac{\bar{\bar{V}}}{H}\frac{\partial y}{\partial \eta}\right)\sqrt{g_s}\Big|_i - U\left(\frac{U}{H}\frac{\partial y}{\partial \xi}+\frac{\bar{\bar{V}}}{H}\frac{\partial y}{\partial \eta}\right)\sqrt{g_s}\Big|_{i-1}}{\Delta \xi}\right.$$

$$\left.+\frac{\bar{\bar{V}}\left(\frac{U}{H}\frac{\partial y}{\partial \xi}+\frac{\bar{\bar{V}}}{H}\frac{\partial y}{\partial \eta}\right)\sqrt{g_v}\Big|_{j+1/2} - \bar{\bar{V}}\left(\frac{U}{H}\frac{\partial y}{\partial \xi}+\frac{\bar{\bar{V}}}{H}\frac{\partial y}{\partial \eta}\right)\sqrt{g_v}\Big|_{j-1/2}}{\Delta \eta}\right]$$

$$\frac{+\frac{\partial y}{\partial \eta}}{g_s H}\;\frac{U\left(\frac{U}{H}\frac{\partial x}{\partial \xi}+\frac{\bar{\bar{V}}}{H}\frac{\partial x}{\partial \eta}\right)\sqrt{g_s}\Big|_i - U\left(\frac{U}{H}\frac{\partial x}{\partial \xi}+\frac{\bar{\bar{V}}}{H}\frac{\partial x}{\partial \eta}\right)\sqrt{g_s}\Big|_{i-1}}{\Delta \xi}$$

$$\left.+\frac{\bar{\bar{V}}\left(\frac{U}{H}\frac{\partial y}{\partial \xi}+\frac{\bar{\bar{V}}}{H}\frac{\partial x}{\partial \eta}\right)\sqrt{g_v}\Big|_{j+1/2} - \bar{\bar{V}}\left(\frac{U}{H}\frac{\partial x}{\partial \xi}+\frac{\bar{\bar{V}}}{H}\frac{\partial x}{\partial \eta}\right)\sqrt{g_v}\Big|_{j-1/2}}{\Delta \eta}\right]$$

For flow in the negative x-direction, the finite differences are taken between cells *i+1* and *i* in accordance with the pigpen method, and the equations are similar to those shown above.

Y-Momentum

For flow in the positive y-direction, the finite differences ar taken between cells $j\text{-}1$ and j in accordance with the pigpen method:

$$\frac{\frac{\partial x}{\partial \xi}}{g\sqrt{H}}\left[\frac{\bar{\bar{U}}\left(\frac{\bar{\bar{U}}}{H}\frac{\partial y}{\partial \xi}+\frac{V}{H}\frac{\partial y}{\partial \eta}\right)\sqrt{g_{22}}\Big|_{i+\frac{1}{2}}-\bar{\bar{U}}\left(\frac{\bar{\bar{U}}}{H}\frac{\partial y}{\partial \xi}+\frac{V}{H}\frac{\partial y}{\partial \eta}\right)\sqrt{g_{22}}\Big|_{i-\frac{1}{2}}}{\Delta \xi}\right.$$

$$\left.+\frac{V\left(\frac{\bar{\bar{U}}}{H}\frac{\partial y}{\partial \xi}+\frac{V}{H}\frac{\partial y}{\partial \eta}\right)\sqrt{g_{11}}\Big|_{j}-V\left(\frac{\bar{\bar{U}}}{H}\frac{\partial y}{\partial \xi}+\frac{V}{H}\frac{\partial y}{\partial \eta}\right)\sqrt{g_{11}}\Big|_{j-1}}{\Delta \eta}\right]$$

$$-\frac{\frac{\partial y}{\partial \xi}}{g\sqrt{H}}\left[\frac{\bar{\bar{U}}\left(\frac{\bar{\bar{U}}}{H}\frac{\partial x}{\partial \xi}+\frac{V}{H}\frac{\partial x}{\partial \eta}\right)\sqrt{g_{22}}\Big|_{i+\frac{1}{2}}-\bar{\bar{U}}\left(\frac{\bar{\bar{U}}}{H}\frac{\partial x}{\partial \xi}+\frac{V}{H}\frac{\partial x}{\partial \eta}\right)\sqrt{g_{22}}\Big|_{i-\frac{1}{2}}}{\Delta \xi}\right.$$

$$\left.+\frac{V\left(\frac{\bar{\bar{U}}}{H}\frac{\partial x}{\partial \xi}+\frac{V}{H}\frac{\partial x}{\partial \eta}\right)\sqrt{g_{11}}\Big|_{j}-V\left(\frac{\bar{\bar{U}}}{H}\frac{\partial x}{\partial \xi}+\frac{V}{H}\frac{\partial x}{\partial \eta}\right)\sqrt{g_{11}}\Big|_{j-1}}{\Delta \eta}\right]$$

Dispersion

The dispersion terms in the x- and y-momentum equations are given as:

X-Momentum

$$A_H\left(\frac{\partial^2 U}{\partial x^2}+\frac{\partial^2 U}{\partial y^2}\right)$$

Y-Momentum

$$A_H\left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2}\right)$$

These expressions are represented in the transformed plane as:

X-Momentum

$$
\begin{aligned}
& U_{\xi\xi}H_{11} + 2U_{\xi\eta}H_{12} + U_{\eta\eta}H_{22} \\
& + (D_{11}^1 U)_\xi H_{11} + (D_{11}^1 U)_\eta H_{12} + (D_{12}^1 U)_\xi H_{12} + (D_{12}^1 U)_\eta H_{22} \\
& + (D_{12}^1 V)_\xi H_{11} + (D_{12}^1 V)_\eta H_{12} + (D_{22}^1 V)_\xi H_{12} + (D_{22}^1 V)_\eta H_{22} \\
& - U_\xi (D_{12}^1 H_{12} + D_{22}^1 H_{22}) \\
& + U_\eta (D_{11}^1 H_{12} + D_{12}^1 H_{22} - D_{11}^2 H_{11} - 2D_{12}^2 H_{12} - D_{22}^2 H_{22}) \\
& + V_\xi (D_{12}^1 H_{11} + D_{22}^1 H_{12}) + V_\eta (D_{12}^1 H_{12} + D_{22}^1 H_{22}) \\
& + [(D_{12}^1 D_{12}^1 + D_{22}^1 D_{12}^2 - D_{22}^1 D_{11}^1 - D_{22}^2 D_{12}^1) H_{22} - (D_{12}^1 D_{12}^2 - D_{11}^2 D_{22}^1) H_{12}] U \\
& + [(D_{12}^1 D_{12}^2 - D_{11}^2 D_{22}^1) H_{11} - (D_{12}^1 D_{12}^1 + D_{22}^1 D_{12}^2 - D_{22}^1 D_{11}^1 - D_{22}^2 D_{12}^1) H_{12}] V
\end{aligned}
$$

where

$$U_\xi = \frac{\partial U}{\partial \xi} \qquad V_\xi = \frac{\partial V}{\partial \xi}$$

$$U_\eta = \frac{\partial U}{\partial \eta} \qquad V_\eta = \frac{\partial V}{\partial \eta}$$

$$U_{\xi\xi} = \frac{\partial^2 U}{\partial \xi^2} \qquad V_{\xi\xi} = \frac{\partial^2 V}{\partial \xi^2}$$

$$U_{\xi\eta} = \frac{\partial^2 U}{\partial \xi \partial \eta} \qquad V_{\xi\eta} = \frac{\partial^2 V}{\partial \xi \partial \eta}$$

$$U_{\eta\eta} = \frac{\partial^2 U}{\partial \eta^2} \qquad V_{\eta\eta} = \frac{\partial^2 V}{\partial \eta^2}$$

H_{ij} = *inverse metric tensor components*

D_{ij}^k = *Christoffel symbols of the second kind*

$(D_{ij}U)_\xi$ = *derivative with respect to* ξ

$(D_{ij}U)_\eta$ = *derivative with respect to* η

$(D_{ij}V)_\xi$ = *derivative with respect to* ξ

$(D_{ij}V)_\eta$ = *derivative with respect to* η

Y-Momentum

$$
\begin{aligned}
&V_{\xi\xi}H_{11} + 2V_{\xi\eta}H_{12} + V_{\eta\eta}H_{22} \\
&+ (D_{11}^2U)_\xi H_{11} + (D_{11}^2U)_\eta H_{12} + (D_{12}^2U)_\xi H_{12} + (D_{12}^2U)_\eta H_{22} \\
&+ (D_{12}^2V)_\xi H_{11} + (D_{12}^2V)_\eta H_{12} + (D_{22}^2V)_\xi H_{12} + (D_{22}^2V)_\eta H_{22} \\
&+ U_\xi(D_{11}^2H_{11} + D_{12}^2H_{12}) + U_\eta(D_{11}^2H_{12} + D_{12}^2H_{22}) \\
&+ V_\xi(D_{12}^2H_{11} + D_{22}^2H_{12} - D_{11}^1H_{11} - 2D_{12}^1H_{12} - D_{22}^1H_{22}) \\
&- V_\eta(D_{11}^2H_{11} + D_{12}^2H_{12}) \\
&+ [(D_{12}^2D_{11}^1 + D_{22}^2D_{11}^2 - D_{12}^1D_{11}^2 - D_{12}^2D_{12}^2)H_{12} + (D_{11}^2D_{22}^1 - D_{12}^1D_{12}^2)H_{22}]U \\
&+ [(D_{11}^2D_{22}^1 - D_{12}^1D_{12}^2)H_{12} + (D_{12}^2D_{11}^1 + D_{22}^2D_{11}^2 - D_{12}^1D_{11}^2 - D_{12}^2D_{12}^2)H_{11}]V
\end{aligned}
$$

The treatment of the advective and dispersive terms is different near boundaries. The velocity cross derivative is assumed to be zero near the boundary, and a slip condition exists. This "slip" boundary is assumed for both the advection and dispersion terms.

APPENDIX 6-B: CLHYD DATA SPECIFICATION RECORDS

Model Control Specifications

(Req)	GENSPECS	Specify general title and system of units
(Req)	TIMESPEC	Specify time-related controlling variables
(Opt)	ADDTERMS	Specify optional terms in governing equations
(Opt)	STARTUP	Specify initial conditions

Grid Description

(Req)	GRIDSPEC	Specify general grid characteristics
(C-Opt)	GRIDCORN	Specify x- and y corner points for grid
(C-Opt)	XSTRETCH	Specify x-coordinates to create stretched grid
(C-Opt)	YSTRETCH	Specify y-coordinates to create stretched grid

Physical Characteristics

(Req)	BATHSPEC	Specify characteristics of bathymetry/topography
(Req)	--	Two dimensional array of bathymetric/topographic data
(Opt)	CHNGBATH	Specify changes to the bathymetric/topographic data
(Opt)	XBARRIER	Specify barrier perpendicular to x-axis
(Opt)	YBARRIER	Specify barrier perpendicular to y-axis
(Opt)	FRICTION	Specify character of bottom friction
(Opt)	FRICTABL	Specify entry for depth-variable friction table
(Opt)	CHNGFRIC	Modify the friction values at selected locations

Boundary Conditions

(Opt)	XBOUNDARY	Specify driving boundary perpendicular to x-axis
(Opt)	YBOUNDARY	Specify driving boundary perpendicular to y-axis
(C-Opt)	FUNCTION	Specify driving boundary forcing function
(C-Opt)	CNRECORD	Specify attributes of constituent forcing
(C-Opt)	CONSTIT	Specify harmonic constituent forcing function
(C-Opt)	TERECORD	Specify attributes of tabular elevation forcing
(C-Opt)	TFRECORD	Specify attributes of tabular velocity forcing
(C-Opt)	TABELEV	Specify irregularly spaced tabular elevations

(C-Opt)	TABFLOW	Specify irregularly spaced tabular velocities

Wind-Field Specifications

(Opt)	WINDSPEC	Specify the character of wind-field data
(C-Opt)	TABWINDS	Specify wind-field tabular data

Output Specifications

(Req)	PRWINDOW	Specify location and timing of a print window
(Opt)	RECGAGE	Specify location of recording gage in grid
(Opt)	RECSNAPS	Specify snapshot time(s) for recording
(Opt)	RECRANG	Specify discharge range perpendicular to x-axis

CMS Data Specification: GENSPECS Record: (Req)
Purpose: Specify general title and system of units.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		GENSPECS	Record identifier.
2-9	TITLE	Char *64	(Opt)		A*	General title for simulation.
10	SUNITS	Integer	(Opt)	ENGLISH	ENGLISH METRIC	Declares the system of units for model computations and results.

UNIT	ENGLISH (SI)	METRIC (British)
Length	ft	m
Time	sec	sec
Velocity	ft/sec	m/sec
Discharge	cu ft/sec	cu m/sec
Pressure	ft (of water)	m (of water)

CMS Data Specification: TIMESPEC Record: (Req)
Purpose: Specify time-related controlling variables.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		TIMESPEC	Record identifier.
2	DT	Real	(Req)		+R*	Time-step for simulation (seconds).
3	TUNITS	Char *8	(Opt)	HOURS	HOURS MINUTES SECONDS	Units for all time variables (except where noted).
4	IT1	Integer	(Opt)	1	+I*	Provisional model time-step at the start of the simulation.
5	IT2	Integer	(Opt)	1	+I*	Length of simulation (in time-steps).
6	NFREQ	Integer	(Opt)		+I*	Time interval (in time-steps) for recording time history data (water velocities and free surface elevations)
7	ITBRKINC	Integer	(Opt)	IT2	+I*	Time interval (in time-steps) for saving HOTSTART data.

CMS Data Specification: STARTUP Record: (Opt)
Purpose: Specify inital conditions.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		STARTUP	Record identifier.
2	SELEV	Real	(Opt)	0.	R*	Initial water surface elevation levels. Velocities are initialized to zero.
		(or) Char *8			HOTSTART	Field variables (*S*, u, and v) to be read to start simulation.
3	SECHO	Char *8	(Opt)	SHORT	SHORT	Short report of input and preliminary data to be written.
					DETAILED	Full (detailed) report of input and preliminary data to be written.
4-10	SNAME	Char *56	(Opt)		A*	Name of startup conditions.

CMS Data Specifiaction: ADDTERMS Record: (Opt)
Purpose: Specify optional terms in governing equations.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		ADDTERMS	Record identifier.
2	ADVFLAG	Char *8	(Opt)	NO	NO	No advective (inertial) terms.
					YES	Advective terms to be included.
3	DIFFLAG	Char *8	(Opt)	NO	NO	No diffusion (eddy viscosity) terms.
					YES	Diffusion terms to be included.
4	AH	Real	(C-opt)	0.	+R*	The diffusion coefficient (required if YES specified for DIFFLAG).
5	COR	Real	(Opt)	0.	+R*	Coriolis coefficient.

Notes:
(1) All terms on this record are omitted from the Governing Equations if this record is omitted.

CMS Data Specification: GRIDSPEC Record: (Req)
Purpose: Specify general computational grid characteristics.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		GRIDSPEC	Record identifier.
2	GRTYPE	Char *8	(Opt)	RECTANG	RECTANG	Cartesian system with constant-spaced grid cells.
					RSTRETCH	Cartesian system with stretching function employed to create grid cells. (requires XSTRETCH and YSTRETCH records after the GRIDSPEC).
					CURVILIN	Curvilinear grid system (requires GRIDCORN record after the GRIDSPEC).
3	GUNITS	Char *8	(Opt)	ENGLISH	ENGLISH METRIC	System of units for grid data.
4	ICELLS	Integer	(Req)		+I*	Number of grid cells in x-direction.
5	JCELLS	Integer	(Req)		+I*	Number of grid cells in y-direction.
6	ALXREF	Real	(Req)		+R*	Overall length of grid in x-direction (in GUNITS).
7	ALYREF	Real	(Req)		+R*	Overall length of grid in y-direction (in GUNITS).
8	XMAP	Real	(Req)		R*	Map scale.

CMS Data Specification: XSTRETCH and YSTRETCH Records: (C-opt)

Purpose: Specify the data to create grid coordinates in a stretched rectilinear cartesian coordinate system.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		XSTRETCH YSTRETCH	Record identifier. (for X-coordinates) (for Y-coordinates)
2	ALPHAB	Integer	(Req)		I*	Alpha at beginning of grid subregion.
3	ALPHAE	Integer	(Req)		I*	Alpha at end of grid subregion.
4-5	A	Real	(Req)		R*	Stretching coefficients used to determine the X- and Y- coordinates in this grid subregion employing a power funtion of the form:
6-7	B	Real	(Req)		R*	
8-9	C	Real	(Req)		R*	X (or) Y = A + B * (ALPHA ** C)

Notes:

(1) Use one record per grid subregion (must be sequential..ie..Regionl, Reqion2...etc.).
(2) These records may be generated by MAPIT in the CMSGRID package.
(3) These records are required if RSTRETCH was specified for GRTYPE on GRIDSPEC record.
(4) A, B, and C use a special format: each should be G16.9 (occupies two fields).

CMS Data Specification: GRIDCORN Record: (C-opt)
Purpose: Specify general characteristics of the curvilinear grid coordinate data.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		*GRIDCORN*	Record identifier.
2	CSEQ	Char *8	(Opt)	XY	XY -XY X-Y -X-Y YX -YX Y-X -Y-X	The 2-D array of grid coordinate data that follows this record is read in a sequence specified by this mnemonic code (see notes for the conventions represented by these mnemonics).
3-4	CFORM	Char *16	(Opt)	(8G10.3)	A*	Format used to read the following 2-D array of grid coordinate data.

(Continued)

(Concluded)

Notes:

(1) Conventions for 2-D array read sequence mnemonics:

```
****************** SEQ - XY *******************
        DO 1 J-1,JCELLS+1
  1     READ(LUN,FORM) (XCT(I,J),I-1,ICELLS+1)
        DO 11 J-1,JCELLS+1
 11     READ(LUN,FORM) (YCT(I,J),I-1,ICELLS+1)

***************** SEQ - -XY ******************
        DO 2 J-1,JCELLS+1
  2     READ(LUN,FORM) (XCT(I,J),I-ICELLS+1,1,-1)
        DO 12 J-1,JCELLS+1
 12     READ(LUN,FORM) (YCT(I,J),I-ICELLS+1,1,-1)

***************** SEQ - X-Y ******************
        DO 3 J-JCELLS+1,1,-1
  3     READ(LUN,FORM) (XCT(I,J),I-1,ICELLS+1)
        DO 13 J-JCELLS+1,1,-1
 13     READ(LUN,FORM) (YCT(I,J),I-1,ICELLS+1)

***************** SEQ --X-Y ******************
        DO 4 J-JCELLS+1,1,-1
  4     READ(LUN,FORM) (XCT(I,J),I-ICELLS+1,1,-1)
        DO 14 J-JCELLS+1,1,-1
 14     READ(LUN,FORM) (YCT(I,J),I-ICELLS+1 1,-1)

***************** SEQ - YX *******************
        DO 5 I-1,ICELLS+1
  5     READ(LUN,FORM) (XCT(I,J),J-1,JCELLS+1)
        DO 15 I-1,ICELLS+1
 15     READ(LUN,FORM) (YCT(I,J),J-1,JCELLS+1)

***************** SEQ - -YX ******************
        DO 6 I-1,ICELLS+1
  6     READ(LUN,FORM) (XCT(I,J),J-JCELLS+1,1,-1)
        DO 16 I-1,ICELLS+1
 16     READ(LUN,FORM) (YCT(I,J),J-JCELLS+1,1,-1)

***************** SEQ - Y-X ******************
        DO 7 I-ICELLS+1,1,-1
  7     READ(LUN,FORM) (XCT(I,J),J-1,JCELLS+1)
        DO 17 I-ICELLS+1,1,-1
 17     READ(LUN,FORM) (YCT(I,J),J-1,JCELLS+1)

**************** SEQ - -Y-X ******************
        DO 8 I-ICELLS+1,1,-1
  8     READ(LUN,FORM) (XCT(I,J),J-JCELLS+1,1,-1)
        DO 18 I-ICELLS+1,1,-1
 18     READ(LUN,FORM) (YCT(I,J),J-JCELLS+1,1,-1)
```

CMS Data Specification: BATHSPEC Record: (Req)
Purpose: Specify general characteristics of the bathymetry/topography data.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		BATHSPEC	Record identifier.
2	BUNITS	Char *8	(Opt)	FEET	FEET METERS FATHOMS	Declares the units for the following bathymetry/topography data.
3	WDATUM	Real	(Opt)	0.	R*	Positive values of bathymetry (depths) are added to this datum value (in BUNITS)
4	LDATUM	Real	(Opt)	0.	R*	Negative values of topography are added to this datum (in BUNITS).
5	DLIMIT	Real	(Opt)	6000. ft	R*	A limiting water depth (deeper values are set to this value in BUNITS).
6	BSEQ	Char *8	(Opt)	XY	XY -XY X-Y -X-Y YX -YX Y-X -Y-X	The 2-D array of bathymetry/topography that follows this record is read in a sequence specified by this mnemonic code (see notes for the conventions represented by these mnemonics).
7-8	BFORM	Char *16	(Opt)	(8G10.3)	A*	Format used to read the following 2-D array of bathymetry/topography values.
9-10	BNAME	Char *16	(Opt)		A*	Name of bathymetry/topography set.

(Continued)

(Concluded)

Notes:
(1) The actual 2-D array of bathymetry/topography data follows this record.
(2) Conventions for 2-D array read sequence mnemonics:

```
****************** SEQ = XY *******************
      DO 1 J=1,JCELLS
 1    READ(LUN,FORM) (VAR(I,J),I=1,ICELLS)

***************** SEQ = -XY *******************
      DO 2 J=1,JCELLS
 2    READ(LUN,FORM) (VAR(I,J),I=ICELLS,1,-1)

***************** SEQ = X-Y *******************
      DO 3 J=JCELLS,1,-1
 3    READ(LUN,FORM) (VAR(I,J),I=1,ICELLS)

***************** SEQ =-X-Y *******************
      DO 4 J=JCELLS,1,-1
 4    READ(LUN,FORM) (VAR(I,J),I=ICELLS,1,-1)

***************** SEQ = YX ********************
      DO 5 I=1,ICELLS
 5    READ(LUN,FORM) (VAR(I,J),J=1,JCELLS)

***************** SEQ = -YX *******************
      DO 6 I=1,ICELLS
 6    READ(LUN,FORM) (VAR(I,J),J=JCELLS,1,-1)

***************** SEQ = Y-X *******************
      DO 7 I=ICELLS,1,-1
 7    READ(LUN,FORM) (VAR(I,J),J=1,JCELLS)

**************** SEQ = -Y-X *******************
      DO 8 I=ICELLS,1,-1
 8    READ(LUN,FORM) (VAR(I,J),J=JCELLS,1,-1)
```

CMS Data Specification: CHNGBATH Record: (Opt)
Purpose: Specify changes to the bathymetry data.

Field	Variable	Type	Status	Default	Permitted Data CHNGBATH	Usage
1	CARDID	Char *8	(Req)		CHNGBATH	Record identifier.
2	BATH	Real	(Req)		R*	New bathymetry/topography value (in BUNITS ... the two datum shift values LDATUM and WDATUM will not be applied to this value).
3	X1INDX	Integer	(Req)		I*	Declares the location of the bathymetry /topography value as a point, line, or a rectangular patch in the grid.
4	Y1INDX	Integer	(Req)		I*	
5	X2INDX	Integer	(Opt)	0	I*	
6	Y2INDX	Integer	(Opt)	0	I*	

Note:
(1) Use one CHNGBATH record per value (no changes if this record is omitted).
(2) All CHNGBATH records must follow two-dimensional bathymetry array.

CMS Data Specification: FRICTION Record: (Opt)
Purpose: Specify character of bottom friction.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		FRICTION	Record identifier.
4	FRDEF	Char *8	(Opt)	CONSTANT	CONSTANT	Friction values constant in time and space (constant Manning's n); separate values for "land" and "water" areas permitted (see FRLAND and FRWATER below).
					VARYBATH	Friction values vary with bathymetry (as defined with FRICTABL records following this record).
					TABULAR	Friction values are assigned to each cell and the 2-D array must follow this record.
5	FRLAND	Real	(C-opt)	048 (SI) .040 (British)	+R*	Friction value for all "land" areas. (used only if CONSTANT specified for FRDEF).
6	FRWATR	Real	(C-opt)	.030 (SI) .025 (British)	+R*	Friction value for all "water" areas. (used only if CONSTANT specified for FRDEF).
7	FDMAX	Real	(Opt)	300 ft 100 m	R*	Maximum water depth (in SUNITS) which will exert a change in variable friction.

(Continued)

(Concluded)

8	FSEQ	Char *8	(Opt)	XY	XY -XY X-Y -X-Y YX -YX Y-X -Y-X	The 2-D array of friction values that follows this record is read in a sequence specified by this mnemonic code (see notes for the conventions represented by these mnemonics).
9	FFORM	Char *8	(Opt)	(8G10.3)	A*	Format used to read the following 2-D array of friction values.

Notes:

(1) If this record is omitted, the above default values will be used.

(2) If VARYBATH is selected for FRDEP, the table of friction values versus the depth follows this record as FRICTABL records.

CMS Data Specification: FRICTABL Record: (C-opt)

Purpose: Specify an entry in the friction value versus bathymetry table.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		FRICTABL	Record identifier.
2	FRICT	Real	(Req)		R*	Friction (Manning's n) value (in FRUNITS).
3	FDEPTH	Real	(Req)		R*	Bathymetry value to use for the corresponding friction value (less than or equal to this depth)

Note: Friction values are not interpolated; they are assigned on a "less than or equal" basis governed by the given bathymetry value (in a range down to the next lower valued bathymetry entry); since the first entry (lowest bathymetry value) has no lower limit, all regions with bathymetry values less than this entry will have the friction value entry on the first FRICTABL record.

CMS Data Specification: CHNGFRIC Record: (Opt)
Purpose: Modify the friction values at selected locations.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		CHNGFRIC	Record identifier.
2	FRICT	Real	(Req)		+R*	New friction (Manning's n) value (in FRUNIT).
3	X1INDX	Integer	(Req)		+I*	Declares the location of the new friction value as a point, line, or a rectangular patch of cells in the grid.
4	Y1INDX	Integer	(Req)		+I*	
5	X2INDX	Integer	(Opt)	0	+I*	
6	Y2INDX	Integer	(Opt)	0	+I*	

Notes:
(1) No changes to friction are made if this record is omitted.
(2) Use one CHNGFRIC record for each new friction value (or location).

CMS Data Specification: XBARRIER and YBARRIER Records: (Opt)
Purpose: Specify the location and characteristics of a subgrid-scale barrier.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		XBARRIER	Record identifier. (Aligned perpendicular to X- axis)
					YBARRIER	Record identifier. (Aligned perpendicular to Y- axis)
2	BRPOS1	Integer	(Req)		+I*	Cell indices declaring the barrier location within the grid; Barrier extends from (and includes) cells BRPOS2 to BRPOS3 along the face of cell BRPOS1.
3	BRPOS2	Integer	(Req)		+I*	
4	BRPOS3	Integer	(Req)		+I*	
5-7	BARNAM	Char *24	(Opt)		A*	Barrier name.

Note:
(1) Use one XBARRIER or YBARRIER record per barrier.

CMS Data Specification: XBOUNDRY and YBOUNDRY Record: (OPT)
Purpose: Specify location and character of a driving boundary.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)			Record identifier.
					XBOUNDRY	(Boundary perpendicular to X-axis)
					YBOUNDRY	(Boundary perpendicular to Y-axis)
2	BNDTYP	CHAR *8	(Req)		CONSTELV	All cells of the driving boundary act in unison as a single elevation forcing function.
					INTRPELV	Driving boundary cells vary independently as interpolated from two elevation forcing functions applied at the ends of the boundary segment.
					CONSTDIS	All cells of the driving boundary act in unison as a single discharge forcing function.
					BAROMETR	Driving boundary cells vary independently as determined by the "inverted barometer" effect (from wind-field and pressure data).
					UNIFLUX	Boundary is specified as a "uniform flux" condition.
3	BNPOS1	Integer	(Req)		+I*	Cell indices declaring driving boundary location within the grid: Boundary extends from (and includes) cells BNPOS2 to BNPOS3 along cell BNPOS1.
4	BNPOS2	Integer	(Req)		+I*	
5	BNPOS3	Integer	(Req)		+I*	

(Continued)

(Concluded)

6	BNDFN1	Integer	(C-opt)	+I*	Integer index of forcing function (tabular or harmonic constituent) for CONSTELV, INTRPELV or CONSTDIS type boundaries.
7	BNDFN2	Integer	(C-opt)	+I*	Integer index of 2nd forcing function used for interpolation on a INTRPELV type boundary.
8-10	BNDNAM	Char *24	(Opt)	A*	Boundary name.

Notes:
(1) An XBOUNDRY or YBOUNDRY record is required for each distinct driving boundary.
(2) For BNDTYP of CONSTELV or CONSTDIS, a function must be provided (the same fuction may be shared by several driving boundaries).
(3) For BNDTYP of INTERPELV, two functions must be provided (and again may be shared).

CMS Data Specification: FUNCTION Record: (C-opt)
Purpose: Specify index number and character of driving boundary forcing function.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		FUNCTION	Record identifier.
2	FUNNO	Integer	(Req)		+I*	Index number of Function.
3	FUNTYP	Char *8	(Req)		HARMCNST	Elevation forcing function to be generated using harmonic constituents (two groups of data must follow this record ... CNRECORD and CONSTIT(s)).
					TABELEVS	Elevations are provided in tabular form (two groups of data must follow this record ... TERECORD and TABELEV or 1-D array).
					TABFLOWS	Discharges are provided in tabular form (two groups of data must follow this record ... TFRECORD and TABFLOW or 1-D array).
4	FUNITS	Char *8	(Opt)	FEET	FEET METERS FPS MPS	Declares units for the given elevations or flows (function values).
5	FMULT	Real	(Opt)	1.0	R*	The function values are multiplied by this factor.
6	FDATUM	Real	(Opt)	0.0	R*	The function values are added to this "datum" quantity.

(Continued)

(Concluded)

7	FSHIFT	Real	(Opt)	0.	R*	The function values are shifted in time by this amount (in TUNITS). NOTE: + Shift forward in time - Shift backward in time
8	FEATHR	Real	(Opt)	0.	R*	The function is gradually spline fit from initial conditions (usually zero) to the given function value over the FEATHR period (in TUNITS).

CMS Data Specification: CNRECORD Record: (C-opt)

Purpose: Specify physical coordinates and timing of a constituent forcing function.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		CNRECORD	Record identifier.
2	RLONG	Real	(Opt)	0.	R*	Record longitude (in decimal degrees).
3	RYEAR	Real	(Req)		I*	Year at beginning of record.
4	RMONTH	Real	(Req)		I*	Month at beginning of record.
5	RDAY	Real	(Req)		I*	Day (of month) at beginning of record.
6	RHOUR	Real	(Req)		R*	Hour (of day) at beginning of record.
7-10	RNAME	Char *32	(Opt)		A*	Record name.

Notes:

(1) This record must follow a FUNCTION record if HARMCNST was specified as FUNTYP.

(2) This record must be followed by one or more CONSTIT records.

CMS Data Specification: CONSTIT Record: (C-opt)
Purpose: Specify and quantify a harmonic constituent for a boundary forcing function.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		CONSTIT	Record identifier.
2	CNAME	Char *8	(Req)		A*	Constituent name (see list of 37 available constituents in Table 4-5)
3	CAMP	Real	(Req)		+R*	Constituent amplitude (in FUNITS).
4	CEPOCH	Real	(Req)		R*	Constituent epoch (decimal degrees).

Notes:
(1) Use one CONSTIT record for each constituent to be included in the forcing function.

CMS Data Specification: TERECORD and TFRECORD Record: (C-opt)

Purpose: Specify general information for a tabular elevation (TERECORD) or tabular (TFRECORD) boundary forcing function.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		TERECORD	Record identifier for tabular elevations.
					TFRECORD	Record identifier for tabular flows.
2	RENT	Integer	(C-opt)		+I*	Number of entries in the tabular record.
3	RSTART	Integer	(C-opt)		+I*	Index number of an entry in the tabular record to be used as the start of the record.
4	RRINT	Real	(Req)		+R*	Time interval (in TUNITS) at which entries are recorded (applies to regularly-spaced data to be provided in a 1-D array following this record).
					IRREGINT	Tabular data are provided at irregular intervals (times of individual entries will be specified on TABELEV or TABFLOW records following this record).
5-6	RFORM	Char *16	(Opt)	(8G10.3)	A*	Optional format specifier used for reading tabular data (applies to regularly spaced data provided in a 1-D array following this record ... does not apply if IRREGINT selected for RRINT above).
7-10	RNAME	Char *32	(Opt)		A*	Tabular record name.

(Continued)

(Concluded)

Notes:

(1) This record must follow a FUNCTION record if TABELEVS or TABFLOWS specified for FUNTYP.

(2) If the tabular data are regularly spaced (in time), a 1-D array must follow this record.

(3) If the tabular data are provided at irregular time intervals, one or more TABELEV or TABFLOW records must follow this record.

CMS Data Specification: TABELEV or TABFLOW Records: (C-Opt)

Purpose: Specify the time and value of an entry in an irregularly spaced tabular elevation or flow forcing function.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		TABELEV	Record identifier for a tabular elevation entry.
					TABFLOW	Record identifier for a tabular flow entry.
2	FHR	Real	(Req)		R*	Hour of the tabular entry (hours).
3	FMIN	Real	(Req)		R*	Minute of the tabular entry (minutes).
4	FSEC	Real	(Req)		R*	Second of the tabular entry (seconds).
5	FMAG	Real	(Req)		R*	Value of tabular entry at the above time (in FUNITS).

Notes:

(1) Use one TABELEV or TABFLOW record for each entry of the tabular forcing function.

CMS Data Specification: WINDSPEC Record: (Opt)
Purpose: Specify the character of wind-field data.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		WINDSPEC	Record identifier.
2	WNTRVL	Char *8	(Opt)		UNIFSTRS	If wind stress is constant with respect to time and space, one TABWINDS record should follow this record.
					UNIFSPED	If wind speed is constant with respect to time and space, one TABWINDS record should follow this record.
					SPVRSTRS	If wind stress varies spatially, this record is followed by one TABWINDS record and wind stress arrays.
					SPVRSPED	If wind speed is varies spatially, this record is followed by one TABWINDS record and wind speed arrays.
					TVRUNIST	If wind stress varies with respect to time, several TABWINDS records follow this record.
					TVRUNISP	If wind speed varies with respect to time, several TABWINDS records follow this record.
					TSPVRSTR	If wind stress varies with respect to time and space, this record is followed by several TABWINDS records. Each TABWINDS record is followed by wind stress arrays.
					TSPVRSPD	If wind speed varies with respect to time and space, this record is followed by several TALWINDS records. Each TABWINDS record is followed by wind speed arrays.

(Continued)

(Concluded)

3	WUNITS	Char *8	(Opt)	FPS	MPH FPS MPS KNOTS	Units for wind values.
8-10	WNAME	Char *24	(Opt)		A*	Wind event name.

Note: (1) No winds are applied to the model if this record is omitted.

CMS Data Specification: TABWINDS Record: (C-opt)
Purpose: Specify wind-field data.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		TABWINDS	Record identifier.
2	IDAY	Integer	(C-opt)		+I*	Day of wind data entry (days).
3	IHOUR	Integer	(C-opt)		+I*	Hour of wind data entry (hours).
4	TAUX	Real	(Req)		R*	X-component of wind stress or speed.
5	TAUY	Real	(Req)		R*	Y-component of wind stress or speed.

CMS Data Specification: PRWINDOW Record: (Opt)
Purpose: Specify location and timing of a print window.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		PRWINDOW	Record identifier.
2	WXCEL1	Integer	(Opt)	1	+I*	Cell indices declaring the grid subregion or window for printing the selected variables. The window will be bounded by (and include) the region from (WXCEL1,WYCEL1) to (WXCEL2,WYCEL2).
3	WXCEL2	Integer	(Opt)	ICELLS	+I*	
4	WYCEL1	Integer	(Opt)	1	+I*	
5	WYCEL2	Integer	(Opt)	JCELLS	+I*	
6	WPRINT	Integer	(Opt)	1	+I*	Time interval (in time-steps) at which the print window is to be recorded.
7	WPRSTR	Integer	(Opt)	1	+I*	Time-step at which print window is to begin recording.
8	WPREND	Real	(Opt)	TMAX	+R*	Time-step at which print window is to end recording.
9-10	WPRVAR	Char *16	(Opt)	EV	E	Water surface elevations.
					V	Water velocities (2 components).
					W	Wind velocities (2 components).
					B	Bathymetry value.
					D	Depth of water column.
					F	Friction value.

Note: Use 1 PRWINDOW record/window (in space or time).

CMS Data Specification: RECGAGE Record: (Opt)
Purpose: Specify location and character of a recording gage in the grid.

Field	Variable	Type	Status	Default	Permitted Data	
1	CARDID	Char *8	(Req)		RECGAGE	Record identifier.
2	IST	Integer	(Req)		+I*	X-index of gage location within grid.
3	JST	Integer	(Req)		+I*	Y-index of gage location within grid.
4-5	STATID	Char *16	(Opt)		A*	Station (or gage) name.

Notes:
(1) Use 1 RECGAGE record per gage.
(2) The interval for recording all gage data was specified by NFREQ on the TIMESPEC record.

CMS Data Specification: RECSNAPS Reocrd: (Opt)
Purpose: Specify snapshot time(s) for recording.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		RECSNAPS	Record identifier.
2	SNPTYP	Char *8	(Req)		INTERVAL	Snapshot data to be recorded at regular time intervals.
3	SXCEL1	Integer	(Opt)	1	+I*	Cell indices declaring the grid subregion or window for printing the selected variables. The window will be bounded by (and include) the region from (SXCEL1,SYCEL1) to (SXCEL2,SYCEL2).
4	SXCEL2	Integer	(Opt)	ICELLS	+I*	
5	SYCEL1	Integer	(Opt)	1	+I*	
6	SYCEL2	Integer	(Opt)	JCELLS	+I*	
7	SNPINT	Integer	(Opt)	1	+I*	Regular time interval (in time-steps) at which snapshot data are to be recorded.
8	SNPSTR	Integer	(Opt)	1	+I*	Time-step at which snapshot recording is to begin.
9	SNPEND	Real	(Opt)	IT2	+I*	Time-step at which snapshot recording is to end.

(Continued)

(Concluded)

---------------------------- Alternate form for specific times --

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		RECSNAPS	Record identifier.
2	SNPTYP	Char *8	(Req)		TIMES	Snapshot data to be recorded at specific times (which follow on this record in fields 3-10).
3-10	SNPTIM	Real	(Req)		+R*	Time-step at which a snapshot is to be recorded (one SNPTIM/field in fields 3-10). Use additional records of this format if more than eight specific times are required.

Notes: (1) Any number of both types of snapshot records may be specified.
(2) Times specified must be integer multiples of DT

CMS Data Specification: XRECRANG and YRECRANG Records: (Opt)
Purpose: Specify location and name of a discharge recording range within the grid.

Field	Variable	Type	Status	Default	Permitted Data	Usage
1	CARDID	Char *8	(Req)		XRECRANG	Record identifier. (Range perpendicular to X-axis)
					YRECRANG	Record identifier. (Range perpendicular to Y-axis)
2	RPOS1	Integer	(Req)		+I*	Cell indices declaring recording range location within the grid: Range extends from (and includes) cells RPOS2 to RPOS3 along the face of cell RPOS1.
3	RPOS2	Integer	(Req)		+I*	
4	RPOS3	Integer	(Req)		+I*	
5-10	RRNAME	Char *45	(Opt)		A*	Range name.

Notes:
(1) Use 1 XRECRANG or YRECRANG record per range.
(2) The time interval for recording range data was specified by NFREQ on the TIMESPEC record.

APPENDIX 6-C: INPUT DATA SET FOR THE INDIAN RIVER INLET EXAMPLE

```
GENSPECS     INDIAN RIVER INLET                                              ENGLISH
GRIDSPECCURVILIN ENGLISH       84        84 66666.6 66666.6      1.0
GRIDCORN       XY  (F12.5,4F16.5)
  3333.33301      5000.00000      6666.66699      8333.33301      10000.0000
  11666.6699      13333.3301      15000.0000      16666.6699      18333.3301
  20000.0000      21666.6699      23333.3301      25000.0000      26666.6699
  28333.3301      30000.0000      31666.6699      33333.3281      35000.0000
  36666.6602      38106.6719      39183.3281      40000.0000      40666.6602
  41250.0000      41770.0000      42226.6719      42636.6719      43003.3281
  43333.3281      43633.3281      43906.6602      44160.0000      44396.6719
  44613.3281      44813.3281      45000.0000      45186.6602      45390.0000
  45610.0000      45846.6602      46100.0000      46373.3281      46666.6602

                                        .
                                        .
                                        .

TIMESPEC      20. SECONDS        1    11340       90
ADDTERMS      YES        NO    0.0          0.00009
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RECGAGE       44      48                MSTAT1
RECGAGE       42      48                MSTAT2
RECGAGE       38      49                MSTAT3
RECGAGE        6       5                VINES GAGE
RECGAGE       16      45                POTNETS GAGE
RECGAGE       36      57                MASSEY GAGE
RECGAGE       58      81                DEWEY GAGE
RECGAGE       63      32                INLET GAGE
RECGAGE       43      48                MSTAT1
RECGAGE       37      50                NSTAT3
RECGAGE       35      50                MSTAT4
RECGAGE       69      27                INLET GAGE3
RECGAGE       69      28                INLET GAGE2
RECGAGE       69      29                INLET GAGE1
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RECRANG XRECRANG      69      26      29
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CHAPTER 7

SHALWV THEORY AND PROGRAM DOCUMENTATION

PART I: INTRODUCTION

1. The Spectral Wave Modeling module of the Coastal Modeling System (CMS) was developed to make the spectral wave models, SHALWV (Resio 1984) and STWAVE (Resio 1990), readily available to field offices within the Corps of Engineers. In the past, engineers needing the modeling power of SHALWV had to contact the model's developers at the Coastal Engineering Research Center (CERC) to run the program for a particular application. Now, SHALWV, as well as STWAVE, may be run by logging into the CMS and conducting a "user friendly," interactive modeling session with the programs.

2. The Spectral Wave Modeling module makes operation of the programs easy and efficient. Pre- and postprocessing routines are included in the module, such that the input files for the programs can be built, the programs can be run, and the results can be immediately displayed and evaluated through menu selections and question-answer sessions. The goal of the operational simplification of the models is to minimize the time required to set up and run the models and maximize the time for evaluating the results.

3. Operating the Spectral Wave Modeling module is largely self explanatory through the existence of on-line help options. However, this user's guide is aimed at providing theoretical background, explaining all of the user's options, as well as the Spectral Wave Modeling module's full capabilities. The following information is covered in this document:

a. Part II briefly discusses the theory, assumptions, limitations, and methodology used in SHALWV and STWAVE.

b. Part III outlines the structure of the Spectral Wave Modeling module.

c. Part IV describes the Spectral Wave Modeling module functions and routines.

d. Part V provides a brief description of the contents of each file used and/or created by the Spectral Wave Modeling module. It also provides a description of the data format required for each file.

PART II: DESCRIPTION OF THE SPECTRAL WAVE MODELING PROGRAMS

Theoretical Foundation

4. SHALWV is the Corp's most versatile spectral wave model. It has the capability of modeling the following applications:

   a. Enclosed bodies of water.
   b. Open coasts.
   c. Arbitrary bathymetry.
   d. Time-varying wind or wave conditions.
   e. Shallow- or deepwater wave growth.
   f. Swell wave transformations.
   g. Fetch- or duration-limited wave growth.
   h. Unlimited fetch and/or unlimited duration wave growth.
   i. Long simulations (e.g. hindcasts).
   j. Rapidly turning winds (e.g. hurricane events).

5. SHALWV numerically simulates growth and decay, as well as propagation, shoaling, refraction, diffraction, and sheltering of a directional wave spectrum over an arbitrary bathymetry. The spectrum is represented two dimensionally in discrete frequency and direction bands. The spectra are modeled in a time-dependent mode, so that most time-varying wave and wind conditions can be simulated. The model operates on a square-celled computational grid and uses the following Courant number stability criterion to determine adequate computational time-steps:

$$\frac{\Delta L}{\Delta t} > C_g(f^*) \tag{7-1}$$

where

ΔL = length of a grid cell

Δt = computational time-step

C_g = group velocity associated with the lowest spectral frequency at the deepest grid point

f^* = lowest spectral frequency value

The Courant number stability criterion assures that wave energy cannot propagate more than one grid cell during a time-step. The water depth is included in Equation 7-1 through C_g defined by:

$$C_g = \frac{1}{2} C \left[1 + \frac{2kh}{\sinh(2kh)}\right] \tag{7-2}$$

where

C = wave celerity

k = wave number = $\frac{2\pi}{L}$

L = wavelength

h = water depth

6. The program employs an explicit upstream finite difference scheme to solve the following spectral balance equation:

$$\frac{\partial \vec{E}}{\partial t} + \vec{\nabla} \cdot (\vec{C}_g \vec{E}) = \vec{S}_{at} + \vec{S}_{nl} + \vec{S}_{ds} + \vec{S}_{wb} + \vec{S}_{br} \tag{7-3}$$

where

E = spectral energy density at (f, θ)

t = time

f = frequency of spectral component

θ = propagation direction of spectral component

S_i = i^{th} source quantity described below

The left-hand side of Equation 7-3 is an expansion of the total derivative of the directional energy density containing a term representing the temporal change in the spectral energy density and terms representing the advection of the spectral wave energy. The right-hand side of Equation 7-2 contains the source terms representing physical mechanisms that add to, or subtract from, net energy in the wave field. These source terms include atmospheric energy input ($\vec{S}_{at}$), nonlinear wave-wave interactions ($\vec{S}_{nl}$), bottom dissipation ($\vec{S}_{wb}$), wave dissipation within the wave field ($\vec{S}_{ds}$), and surf-zone breaking ($\vec{S}_{br}$).

Advection Terms

7. Advection of the wave energy in each discrete frequency-direction band is performed independently. A stepwise solution estimates the wave ray along which the energy contained in each discrete band propagates in order to arrive at the grid point of interest by the end of the time-step (Figure 7-1).

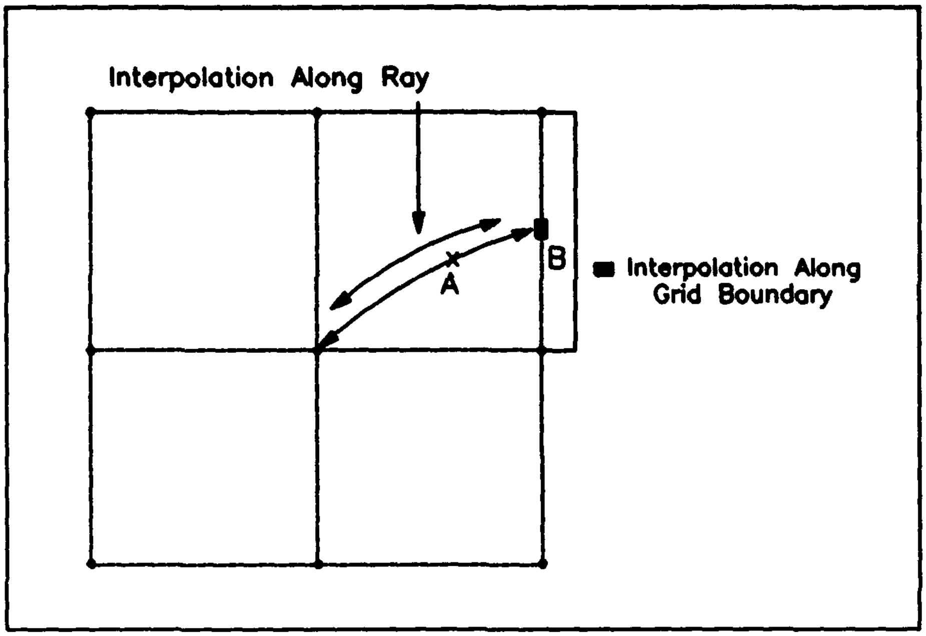


Figure 7-1. Illustration of propagation method

Point A in Figure 7-1 represents the location of the wave energy contained in the discrete frequency-direction band at the beginning of the time-step. An estimate of this energy is obtained by an interpolation method that first projects the wave ray farther back in time until a grid boundary is crossed such as point B in Figure 7-1. This estimated energy is propagated along the wave ray as refraction and shoaling effects are estimated, reaching the grid point C at the end of the time-step. After propagating all energy into point C, energy is added to, or removed from, each discrete energy band by the source terms. At the end of the time-step, the directional spectrum at each grid point is the sum of the independently propagated spectral elements. Since the grid spacing can be large, smooth bathymetry is assumed.

Source Terms

8. The SHALWV model assumes that the primary source mechanisms for storm waves in arbitrary water depths are the atmospheric energy input (as originally proposed by Phillips (1957)), the nonlinear wave-wave interactions, and internal wave field dissipation. The atmospheric source term is formulated such that the energy addition due to wind stress is confined primarily at

the peak of the spectrum and to the higher frequencies of the spectrum regions II and III in Figure 7-2) in deep water. During fully developed conditions where there is no additional wave growth, wind energy cannot be transferred directly to the sea surface.

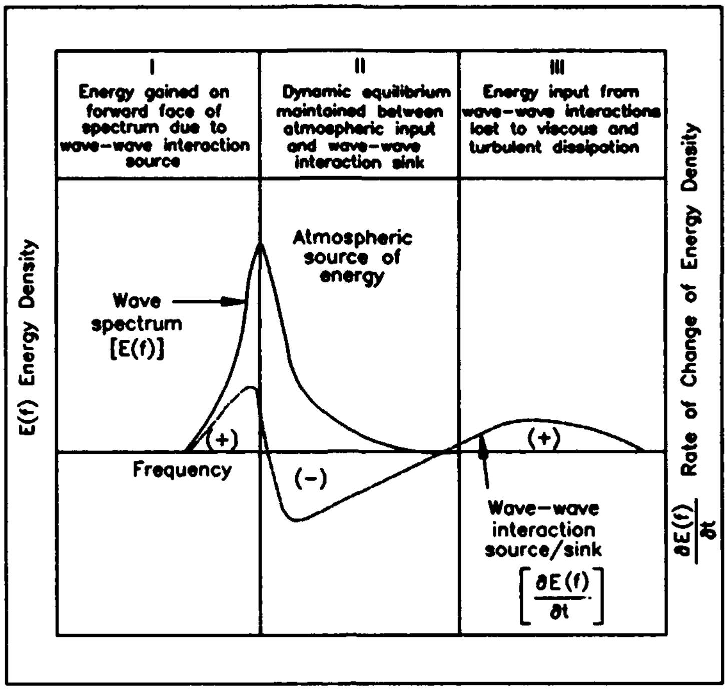


Figure 7-2. Source/sink mechanism for spectral energy transfers

9. As the water depth decreases, the lower frequency waves become nondispersive and begin to travel at a celerity that depends on the depth. SHALWV assumes that as waves approach the nondispersive limit in shallow water, the lower frequencies of the spectrum become incapable of receiving direct atmospheric input, as well as become incapable of receiving energy from the midrange frequencies through wave-wave interactions.

10. The dashed line in Figure 7-2 represents the relocation of wave energy between frequencies via the nonlinear wave-wave interactions (Hasselmann 1962) during active wave growth. Energy is shifted in both directions from region II. Energy shifted to higher frequencies (region III) is dissipated through viscous and turbulent processes. Although wave-wave interaction is a conservative process, the model "loses" this energy by limiting the energy in the higher frequencies of the spectrum to the depth-limited spectral form. Energy shifted to the lower frequencies contributes to wave growth and the shifting of the spectral peak to lower frequencies, which in turn allows

the midrange to accept more energy through atmospheric input. The wave-wave interaction term is sensitive to both the energy contained in the spectrum and the shape of the spectrum.

11. The model contains a procedure for the transformation of swell wave energy that is required when a bimodal spectrum is input at the start of a simulation, when winds are turned-off at some point during the simulation, or when the spectral peak moves out of the growth region. The model calculates the wind sea spectrum at each grid point and subtracts that spectrum from the total energy spectrum. Any remaining energy at frequencies with phase speeds greater than or equal to the wind speed is treated as swell. Then, the peak frequency of the swell and the total swell energy are calculated.

12. Bottom friction and percolation are not considered in the calculation of the wind sea spectrum. However, source terms are present for bottom friction and percolation that allow the user to include these effects for swell. The effect of bottom friction and percolation is to decrease the spectral energy levels due to bottom influences. The effect of bottom friction on and percolation is accounted for in the wind sea balance through the empirical TMA (Hughes 1984) relationships for wave growth.

Diffraction and Sheltering

13. In nature, energy propagating toward a point directly behind an obstruction, such as an island, may be blocked by the obstruction. However, some of the energy may still reach the sheltered point due to diffraction around the obstruction. Diffraction around obstructions is included in SHALWV by implementation of a scheme presented by Penny and Price (1952) and Wiegel (1962). This method applies Sommerfeld's solution for diffraction of light waves at the edge of a semi-infinite screen to water-wave diffraction at the edge of a semi-infinite breakwater. The assumptions are that linear wave theory applies, water depths are uniform, and the breakwater is semi-infinite and provides complete reflection.

14. Obstructions such as islands are represented in SHALWV as grid points defined as land. (See question GF-22 in Part IV and the Land/Water File description in Part V.) Thus, wave energy is allowed only to propagate around these points, not through them. The diffraction option in SHALWV can

be used to improve the calculation of energy that propagates into the region behind an obstruction.

15. Due to the computational scheme used in SHALWV, certain cautions must be applied when specifying the size, shape, and diffracting effect of an obstruction. Figure 7-3 shows three different specifications for an obstruction. Figure 7-3a is an obstruction specified by a single land point. The lengths of the wave propagation vectors indicate the relative amount of energy diffracting into the region behind the obstruction. Figure 7-3b shows an obstruction specified by two adjacent land points. In this case, the land points will not block energy propagating between the points. They block only the energy that tries to pass directly through the points. Two or more adjacent points are required as shown in Figure 7-3c to provide complete blocking of energy between points.

16. Since many obstructions are very irregular in shape or are small compared with the user's computational grid spacing, using three or more points to block wave energy at a location is not always logical. Hence, SHALWV has an additional option for sheltering (or blocking) wave energy at given locations. Sheltering by obstructions is achieved through an array of sheltering coefficients that represent the percentage of energy in each spectral direction band (see question GF-6 and GF-7 in Part IV) allowed to reach a grid point. For points around islands that experience sheltering, the coefficients can be defined for every angle band.

Initial and Boundary Conditions

17. SHALWV contains a feature that allows the user to initialize each grid point with a specified TMA directional wave energy spectrum at the start of a simulation. These spectra are called initial conditions. Additionally, SHALWV contains a feature that allows the incoming wave energy at the boundaries of the computational grid to be updated during the simulation to represent the actual prototype conditions and to prevent unrealistic loss of wave energy through the side boundaries, such as in an open coast application. These are called boundary conditions. The program BCGEN is included in the Spectral Wave Modeling module to generate the initial and boundary conditions for SHALWV.

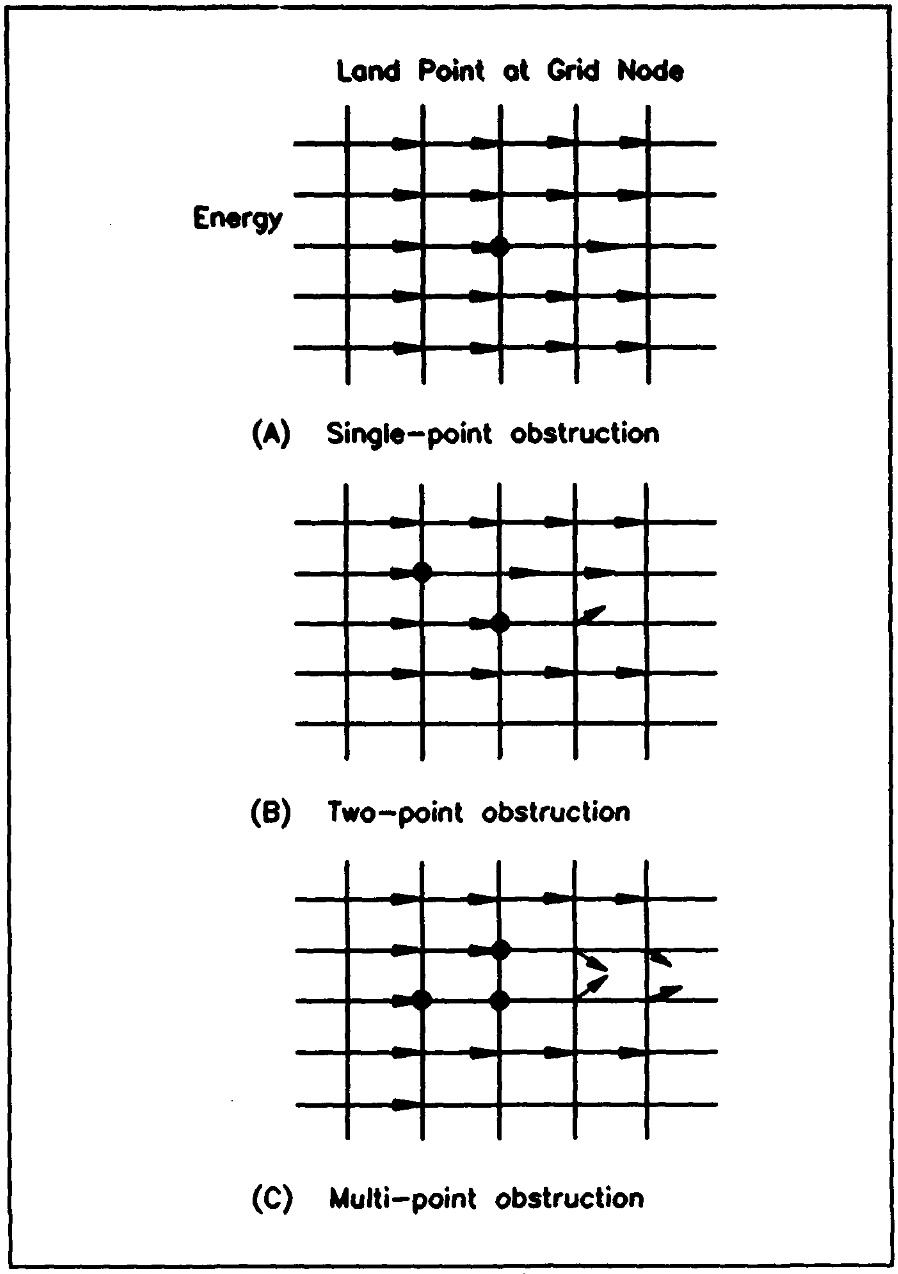


Figure 7-3. Representation of obstructions on the SHALWV computational grid

Preprocessing Options

18. SHALWV contains a cost- and time-saving feature that allows users to preprocess time-independent elements of the SHALWV simulation when several similar simulations are planned. The preprocessing option computes the time-independent characteristics of the simulation, such as the phase and group velocities of each spectral energy band. If the discretization of the energy

spectrum and the bathymetry data remain unchanged between simulations, then the time-independent characteristics can be preprocessed once for all simulations and stored in a file. Then, during the simulations, only the time-dependent characteristics are computed, while the time-independent data are read from a file.

Warm Starts

19. When long simulations must be run, such as long-duration hindcasts, multiple SHALWV simulations might be required. For example, to simulate a 1-year hindcast, twelve 1-month simulations might be performed. To maintain consistency between one simulation and the next, wind and wave information for the last time-step of the first simulation is used to initialize wind and wave conditions for the second simulation, etc. Because the wind and wave information is initialized in the second and subsequent simulations, they are said to have "warm starts." Figure 7-4a shows example results of a segmented simulation when warm starts are not used, while Figure 7-4b shows example results when warm starts are used. SHALWV and the Spectral Wave Modeling module are configured to facilitate multiple simulations using "warm starts." (See question GF-26 in Part IV)

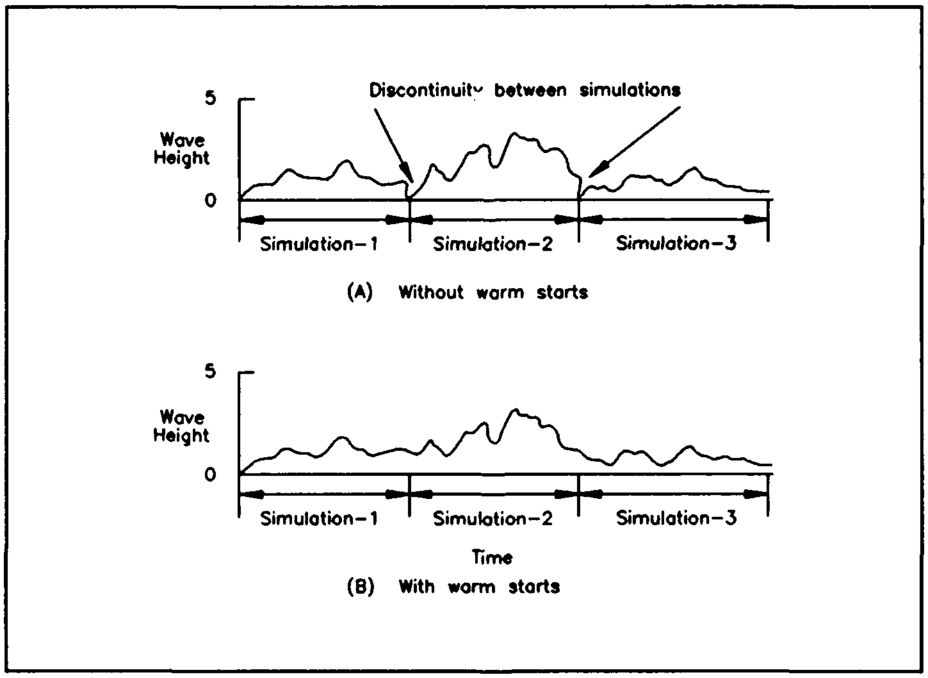


Figure 7-4. Examples of wave simulation results with and without warm starts for a long segmented simulation

Computational Grids and Subgrids

20. The computational grid required by SHALWV must contain square grid cells. The columns of the grid should be oriented north-south and the rows oriented east-west. The SHALWV has no provision to include curvature effects of the Earth, so the grid must have an expanse generally less than 20° in latitude and longitude. Figure 7-5 shows the computational grid orientation convention.

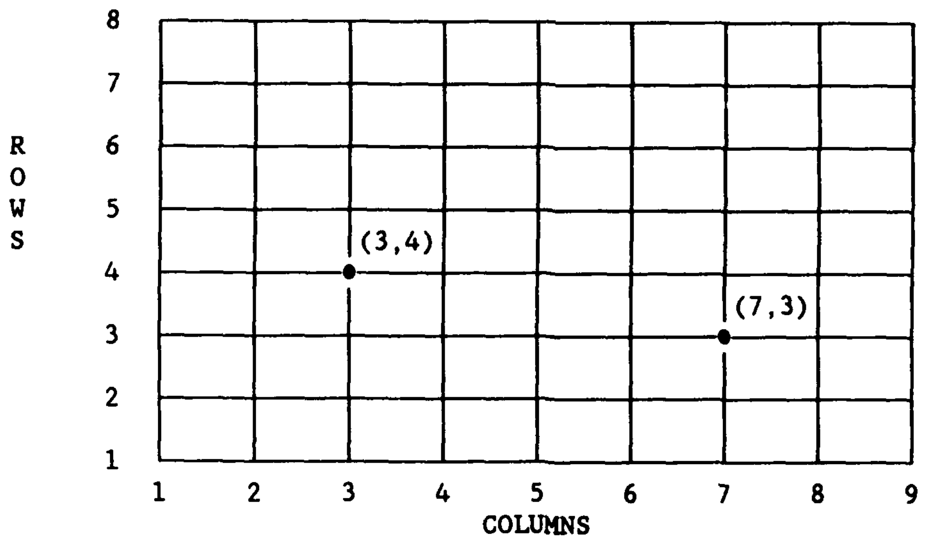
21. When input boundary conditions are not available, SHALWV may require that a large water body be modeled even though the user is only interested in a small portion of the water body. Modeling the large water body is necessary to determine the wave conditions that propagate into the region of interest from other regions. However, modeling the large water body reduces the resolution of SHALWV's results in the region of interest. To improve the model resolution, subgrids may be used which refine the original grid as shown in Figure 7-6. The method of applying subgrids is as follows. First, the large water body is modeled with a large computational grid (grid cells are large). While the large water body is modeled, wave information is saved at locations around the region that will be modeled with a subgrid (see example locations in Figure 7-6). The saved information is then used as input boundary conditions for the subgrid simulation. The subgrid simulation period is the same as the original simulation period except that the computations are concentrated only in the region of the subgrid. The input boundary conditions generated during the original simulation are used to drive the subgrid simulation.

Assumptions and Limitations of SHALWV

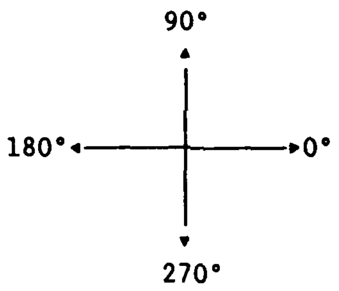
22. Although the SHALWV program is the Corps of Engineers' most versatile arbitrary water depth wave model, it was created with certain assumptions and limitations, like all programs. The SHALWV's inherent assumptions and limitations are listed below:

Assumptions

a. The source term for high-frequency wave dissipation can be represented by limiting the shape of the wave spectrum.



GRID CONVENTION



DIRECTION CONVENTION

NOTE: When grid information is entered in matrix form (as from a file), then the first line of data corresponds to ROW 8 on the grid above.

Figure 7-5. Orientation convention for the computational grid

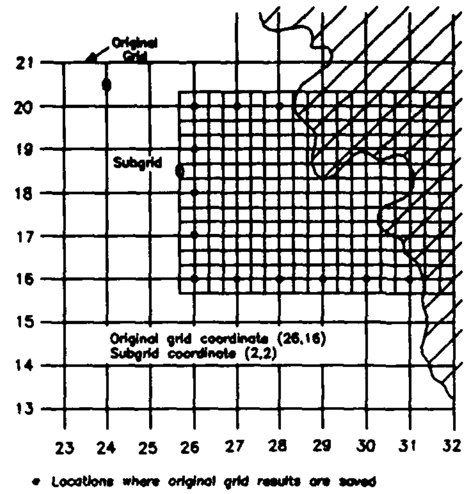


Figure 7-6. Relationship between an "original" computational grid and a subgrid

b. The bathymetry between grid nodes is linear.

c. Refraction can be computed based on the change in depth between the deepwater input boundary and point of interest.

d. Bottom friction and percolation are significant only when considering swell waves.

e. The lower frequencies of the wave energy spectrum do not receive energy input from the atmosphere when these waves are in the nondispersive, shallow-water region.

f. A TMA (Hughes 1984) spectral shape limits the sea wave spectrum.

g. Wave growth is adequately represented by the Joint North Sea Wave Program (JONSWAP) wave growth criteria (Hasselmann et al. 1976).

Limitations

a. Wave-current interactions are not represented.

b. The variation of the still-water level with time is not represented (e.g. storm surge).

c. Variable grids or boundary-fitted grids cannot be used.

d. Numerical stability depends on the Courant number criterion.

e. The Earth's curvature is neglected. Therefore, only a portion of the ocean's surface may be modeled during a given simulation.

PART III: STRUCTURE OF THE SPECTRAL WAVE MODELING MODULE

Introduction

23. The Spectral Wave Modeling Module of CMS contains two operational branches. The branch containing the SHALWV program is used when time-varying spectral wave problems are addressed, and the branch containing the STWAVE program is used when time-invariant spectral wave problems are addressed. Time-varying problems include cases where the growth of wave conditions is important, i.e., wind, sea, and swell vary over time. Time-invariant problems include cases where the transformation of design wave conditions near a project site are of interest.

24. The Spectral Wave Modeling Module of CMS makes execution of SHALWV and STWAVE simple by removing the burden of organizing data and files. When a user begins a modeling session with the Spectral Wave Modeling Module, the operational branch (STWAVE or SHALWV) must be selected. The module then leads the user through an interactive session of file building, wave simulations, and/or output data processing. The module prompts the user for all of the information pertinent to the particular function and routine being used. For the simplest applications, the only item a user needs during use of the module is a bathymetric map of the region of interest. Descriptions of the information required by each function and routine is provided in Part IV.

25. The SHALWV and STWAVE branches of the module are similar. Both branches have basic functions to build input files, run module programs, and postprocess results. Also, the selection menus used in each branch are similar. Although the two branches of the module are similar, the specific aspects of each program are discussed separately to make this user's guide more convenient while working with one program or the other. The general structure of the Spectral Wave Modeling module is illustrated in Figure 7-7.

Operational Structure of the SHALWV Branch

26. The operational functions of the SHALWV branch of the Spectral Wave Modeling module are illustrated in Figure 7-8. The file-building function must be used prior to the function to run programs, and the function to run programs must be used prior to the function to postprocess the model results.

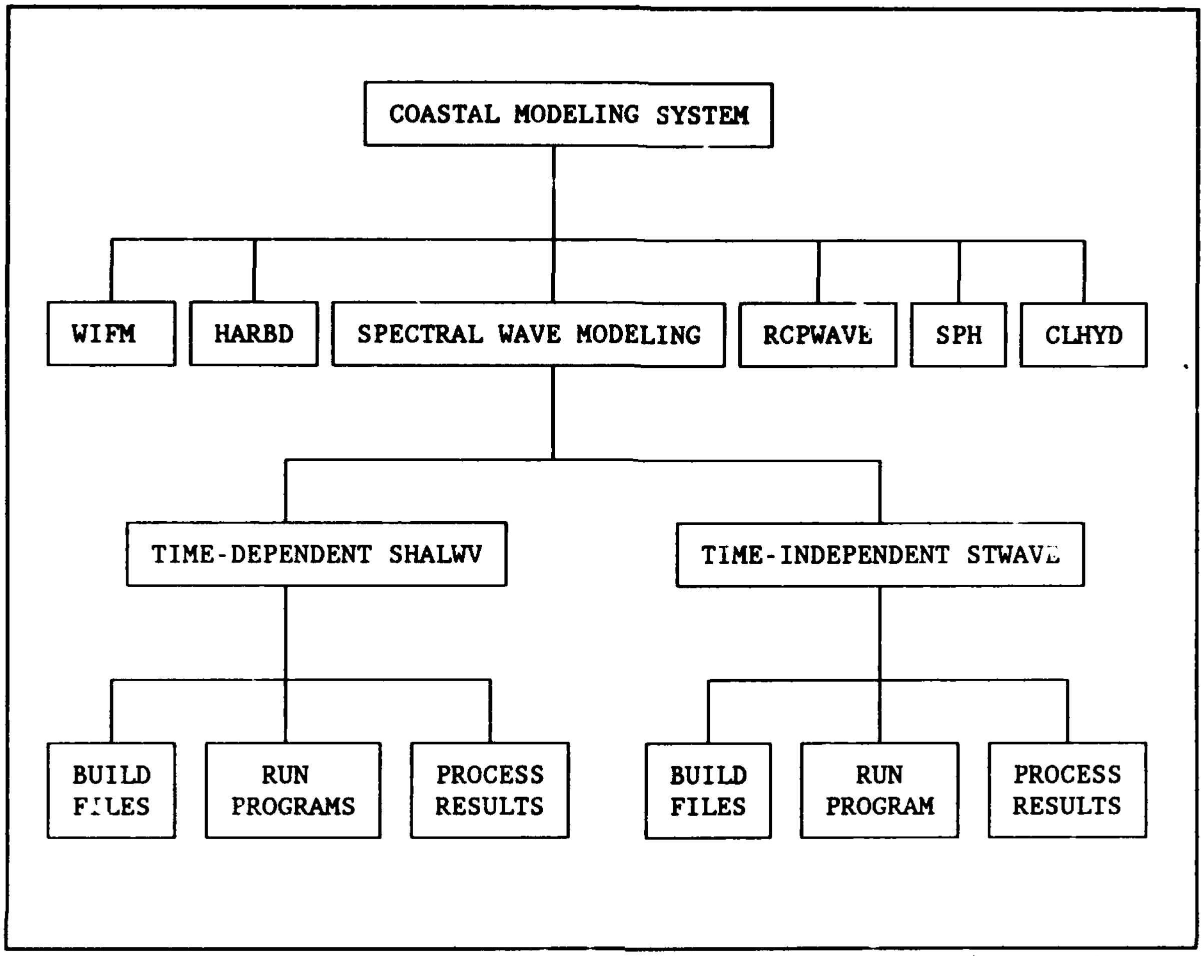


Figure 7-7. General structure of the Spectral Wave Modeling module of CMS

Figures 7-9 through 7-11 indicate the files created and used by each routine within each function of the SHALWV branch. The coordination between the functions and the routines within each function can be followed by observing which routines create what files, as well as which routines use those files. Each file has an associated identifying letter and number. Files that are required for input are identified with the letter "R".

27. Files that are automatically created are identified with the letter "A," and files that are optionally created or required are identified with the letter "O." The contents and format of data within each file are described in Part V.

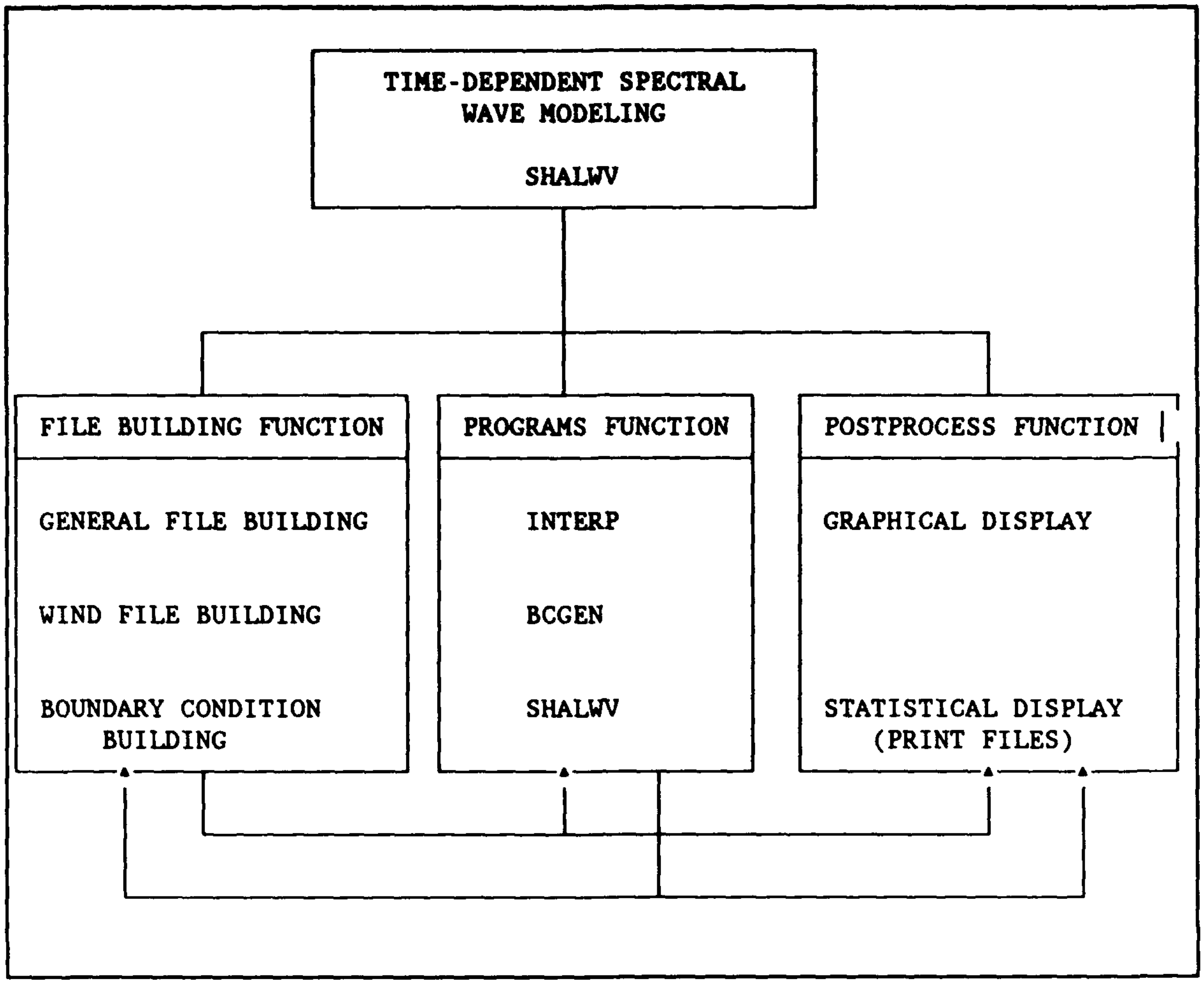


Figure 7-8. Organization of functions and routines within the SHALWV branch of the Spectral Wave Modeling module

OPTION *	FILE #	FILE BUILDING ROUTINE: INPUT FILES		OUTPUT FILES	OPTION *	FILE #
0	1	OLD GENERAL INPUT FILE (SHALWVIN.SWV)	GENERAL FILE BUILDING	GENERAL INPUT FILE (SHALWVIN.SWV)	A	1
0	2	BATHYMETRY FILE (USER SPECIFIED NAME)		BATHYMETRY FILE (DEPVARI.SWV, OR USER-SPECIFIED NAME)	A	2
0	3	LAND/WATER MATRIX FILE (USER SPECIFIED NAME)		SHELTERING DATA FILE (SHELTER.SWV OR USER-SPECIFIED NAME)	A	5
0	4	DIFFRACTION DATA FILE (USER SPECIFIED NAME)		SUBGRID INTERPOLATION FILE (INTRPIN.SWV)	0	6
0	5	SHELTERING DATA FILE (USER SPECIFIED NAME)		PARAMETER INCLUDE FILE (FILE1.SWV)	A	18
0	5	SHELTERING DATA FILE (USER-SPECIFIED NAME)		FILE NAME FILE (FILENMI.SWV)	A	19
0	7	GENERAL INPUT FILE (SHALWVIN.SWV)	WIND FILE BUILDING	WIND DATA FILE (USER SPECIFIED + .WND)	A	8
0	9	FILE NAME FILE (FILEMI.SWV)		WIND FILE NAME FILE (FILENMW.SWV)	A	20
0	7	WIND INTERPOLATION FILE (USER-SPECIFIED)				
R	19	FILE NAME FILE (FILENMI.SWV)	BOUNDARY CONDITION FILE BUILDING	BCGEN INPUT FILE (BOUNDIN.SWV)	A	10
R	1	GENERAL INPUT FILE (SHALWVIN.SWV)				
R	2	BATHYMETRY FILE (DEPCONST.SWV, DEPVORI.SWV OR USER-SPECIFIED				
0	9	SPECTRAL DATA FILE (USER-SPECIFIED)				

*A = Automatically Created Output File
0 = Optionally Created or Required File
R = Required Input File

Figure 7-9. File Building Routines

OPTION *	FILE *	RUN PROGRAMS ROUTINE			OPTION *	FILE *
R	10	BCGEM ONPUT FILE (BOUNDIN.SWV)	RUN BCGEN	BOUNDARY CONDITION FILE (BOUNDOUT.SWV)	A	11
R	6	SUBGRID INTERPOLATION FILE (INTRPIN.SWV)	RUN	BOUNDARY CONDITIOON FILE (BOUNDOUT.SWV)	A	11
R	12	SUBGRID BOUNDARY CONDITION FILE	INTERP	FILENAME FILE (FILENMB.SWV)	A	22
R	5	FILE NAME FILE (FILENMB.SWV)				
R	1	GENERAL INPUT FILE (SHALWVIN.SWV)	RUN	WAVE FIELD FILE (USER-SPECIFIED + .MTX)	A	15
R	2	BATHYMETRY FILE (DEPCONST.SWV, DEPVARI.SWV, OR USER-SPECIFIED	SHALWV	WAVE SPECTRA FILE (USER-SPECIFIED + .SPE)	A	16
				WAVE CHARACTERISTICS FILE (USERSPECIFIED + .SEA)	A	17
R	5	SHELTERING DATA FILE (SHELTER.SWV OR USER-SPECIFIED)		PREPROCESSS FILE (USEER-SPECIFIED + .PRP)	O	13
R	8	WIND DATA FILE (USER-SPECIFIED + .WND)		WARM START FILE (USER SPECIFIED + .WRM)		
O	11	BOUNDARY CONDITION FILE (BOUNDOUT.SWV)		FILENAME FILE (FILENMP.SWV)	O	21
O	13	PREPROCESS FILE (USER-SPECIFIED + .PRP)		FILENAME FILE (FILENMWR.SWV)	O	23
O	14	WARM START FILE (USER-SPECIFIED + .WRM)		FILENAME FILE (FILENMB.SWV)	O	22
O	19	FILE NAME FILE (FILENMI.SWV)		FILENAME FILE (FILENMPST.SWV)	O	24
O	20	FILE NAME FILE (FILENMW.SWV)				
O	21	FILE NAME FILE (FILENMP.SWV)				
O	22	FILE NAME FILE (FILENMB.SWV)				
O	23	FILE NAME FILE (FILENMWR.SWV)				

*A = Automatically Created Output File
O = Optionally Created or Required File
R = Required Input File

Figure 7-10. Run-Programs Function and Routines

OPTION *	FILE #	POST-PROCESSING ROUTINES			OPTION *	FILE #
R R R R R R R	24 19 1 2 15 16 17	FILENAME FILE (FILENMI.SWV) FILENAME FILE (FILENMI.SWV) GENERAL INPUT FILE (SHALWVIN.SWV) BATHYMETRY FILE (DEPCONST.SWV, DEPVARI.SWV, OR USER-SPECIFIED) WAVE FIELD FILE (USER-SPECIFIED + .MTX) WAVE SPECTRA FILE (USER-SPECIFIED + .SPE) WAVE CHARACTERISTICS FILE (USER-SPECIFIED + .SEA)	GRAPHICS	SCREEN DISPLAYS NO FILES		
R R R R R R	24 19 1 15 16 17	FILE NAME FILE (FILENMPST.SWV) FILE NAME FILE (FILENMI.SWV) GENERAL INPUT FILE (SHALWVIN.SWV) WAVE FILE FILE (USER-SPECIFIED + .MTX) WAVE SPECTRA FILE (USER-SPECIFIED + .SPE) WAVE CHARACTERISTICS FILE (USER-SPECIFIED = .SEA)	STATISTICS	WAVE CHARACTERISTICS FILE (USER-SPECIFIED) GENERAL STATISTICS FILE (USER-SPECIFIED) WAVE FIELD OUTPUT FILE (USER-SPECIFIED)	0 0 0	NA NA NA

*A = Automatically Created Output File
0 = Optionally Created or Required File
R = Required Input File

Figure 7-11. Post-Processing Routines

PART IV: MODULE FUNCTIONS AND ROUTINES

SHALWV Module Functions and Routines

28. The first function of the SHALWV branch of the Spectral Wave Modeling module of CMS is to build most or all of the necessary input files for the user's application. The second function is to run SHALWV and related programs. The third function is to display graphically or statistically the results of the user's most recent SHALWV run. Descriptions of the operation of each function and routine and the specific information required by each function and routine are presented in the following sections.

29. The organizational procedures for different types of simulations are presented below:

Simulation #1: Preprocessing time-independent information only; no wave simulations; no warm starts; no subgrids; no input boundary conditions; no output boundary conditions.

Procedure: Run General File Building Routine.

Run SHALWV.

Notes: After the time-independent data are preprocessed by SHALWV, the General File Building Routine is rerun specifying "Calculating Waves Only" instead of preprocessing. No wind or boundary condition data can be processed when "Preprocessing Only" is specified. The wind and boundary condition data are time-dependent and therefore will be specified during the "Calculating Waves Only" simulation, below.

Simulation #2: Calculating Waves Only; no warm starts; no subgrids; no input boundary conditions; no output boundary conditions.

Procedure: Run General File Building Routine.

Run Wind File Building Routine.

Run SHALWV.

Postprocess Results.

Note: A "Calculating Waves Only" simulation is the same as "Preprocessing and Calculating Waves Only" simulation below except that the time-independent data that would be calculated during the SHALWV simulation are read from a file. Therefore, if the "Preprocessing Only" option (Simulation #1) was used prior to "Calculating Waves Only" simulation, Simulations #3 through #7 may also be run using "Calculating Waves Only".

Simulation #3:	Preprocessing and Calculating Waves; no warm starts; no subgrids; no input boundary conditions; no output boundary conditions.
Procedure:	Same as Simulation #2.
Simulation #4:	Same as Simulation #3 except using warm starts.
Procedure:	Same as Simulation #3.
Note:	Warm starts can be used only if a previous simulation used a warm or cold start with the save option. Also when using warm starts, the last wind-field and boundary condition input during the previous simulation must be repeated as the first input of the current simulation.
Simulation #5:	Same as #3 except using subgrids.
Procedure:	Run General File Building Routine.
	Run INTERP.
	Run SHALWV.
	Postprocess Results.
Note:	Subgrids can be used only if a previous simulation saved output boundary conditions at the boundary grid points of the subgrid. Input boundary conditions must come from the previous simulation. Wind information is also obtained from the previous simulation.
Simulation #6:	Same as #3 except with user-specified input boundary conditions.
Procedure:	Run General File Building Routine.
	Run Wind File Building Routine.
	Run Boundary Condition File Building Routine.
	Run BCGEN.
	Run SHALWV.
	Postprocess Results.
Simulation #7:	Same as Simulation #3 except using output boundary conditions (for a subsequent Subgrid Simulation).
Procedure:	Same as Simulation #3.

File building functions

30. The first function of the SHALWV module is to assist users in building the input files required by SHALWV. Users are prompted for input through a series of menu selections and question-answer sessions. It is recommended that the file-building function routines be used whenever possible to minimize potential file format and organizational errors. However, some files may be easier to build externally on the user's preferred word proces-

sor. Such files will be identified. The proper format for the files and definitions of the data that must be included in the files is found in Part V.

31. Three routines can be used to build the necessary input files for SHALWV. The first is the General File-Building routine (Part IV), which builds up to six of the input files required by SHALWV. The files are called:

- a. General Input File.
- b. Bathymetry File.
- c. Sheltering File.
- d. Subgrid-Interpolation File.
- e. Parameter File.
- f. Main File Name File.

All of the files are required for every SHALWV simulation except for the Subgrid-Interpolation File, which is required only for special subgrid applications (described in Part II). The second file-building function routine is the Wind Input File-Building routine (Part IV), which builds the required Wind Data File for SHALWV. (Note: a wind data file is required for all SHALWV runs. If wind input is not desired, the windspeed should be assigned the integer value of (1).) The third file-building function routine is the Boundary Condition File-Building routine (Part IV), which constructs the optional BCGEN Input File. (The BCGEN program is used to generate initial and boundary conditions for SHALWV as described in Parts II and IV).

General file building routine

32. The General File-Building routine is used to construct the required General Input File, Bathymetry File, Sheltering File, Parameter File, and Main File Name File, as well as the optional Subgrid Interpolation File. The General Input File, Bathymetry File, Sheltering File, and Subgrid Interpolation File are briefly described below. All of the files are described in Part V. The General Input File contains the following information:

- a. Program flow control parameters.
- b. Spectral frequencies and direction discretization parameters.
- c. Computational grid parameters.
- d. Land or water identifiers for each grid node.
- e. Node locations for output of model results.
- f. Node locations for input and output boundary condition data.
- g. Diffraction information.

33. The Bathymetry File contains a water depth for each node in the grid. The user may build the file interactively through the General File Building routine, in which the user is prompted for a water depth at each node, or in the case where the depths are constant, the user is prompted for the constant depth value. The user may also build the bathymetry file on a preferred word processor and then specify the name of the file during the General File Building routine. Since the bathymetry file already exists in this case, the General File Building routine will save the name of the file for later use by SHALWV. The format for the bathymetry file is given in Part V.

34. The Sheltering Input File specifies node locations that are sheltered from waves by an obstruction, such as an island or peninsula, and the percentage to which the nodes are sheltered. Similar to the Bathymetry File information, the sheltering information may be entered interactively during the General File Building session or by specifying an existing file that contains the information.

35. The Subgrid Interpolation File is used by the boundary-condition interpolation program, INTERP (see Parts II and V), to reduce boundary conditions obtained from the original SHALWV simulation to the scale of a subsequent subgrid simulation.

Data descriptions for general SHALWV files

36. Descriptions of the data required during the General File Building session are provided below. The descriptions are provided as follows: the "Question:" is provided as it appears on the user's terminal during the interactive file-building session along with an identifying number for reference (e.g. GF-1). Then, a list of "Options:" which may be used to answer the question are provided. If the question requires a limited response, then the range of values allowed is given. A list of previous questions that determine whether the current question is asked is presented under "Preselect:". For example, question GF-6 will not be asked unless the user previously selected option 1 or 3 on question GF-2 and also option 1 on question GF-3. While all of the questions that could be asked by the module are listed below, not all of them will be asked. In fact, no simulation will ever require answers to ALL of the questions. Each question is explained under the "Define:" section, and a list of "Cautions:" are provided to alert users to special requirements of the module. Finally a "PATH:" is provided that indicates which question is next based on your previous option selections.

GF-1 Question : **Enter SCREEN WIDTH OPTION >**

Options : 1 - 80 Characters.

2 - 132 Characters.

Preselect: None.

Define : The setup for the display width of your screen is necessary to keep output matrices from "wrapping" around on the screen or from being truncated on the screen during the summary review of data at the end of the General File Building Session. An incorrect selection will not affect creation of the General Input File.

Caution : If you select a 132-character screen width when screen is only 80 characters, matrix output displayed during input summary at end ofthe General File Building session will be wrapped around on the screen or truncated. This will only affect data viewing and not the data itself.

GF-2 Question : **Enter PROCESS OPTION >**

Options : 1 - Create preprocess file and stop.

2 - Calculate wave field only.

3 - Preprocess and calculate wave field.

Preselect: None.

Define : When multiple simulations of SHALWV are needed, it may be cost and time effective to compute the time-independent variables once for the entire grid and store those values in a preprocess file. Then, when SHALWV is run to compute the wave fields, the time-independent data can be read from the preprocess file, and only the time-dependent variables are computed during the subsequent simulation. When only two or three SHALWV simulations are needed, it may be better to preprocess and run SHALWV in the same execution.

The time-independent variables include the phase and group speed of each discrete spectral energy band. Therefore, if such variables are constant from one simulation to the next (i.e., if the spectral discretization and bathymetry information are not changed), then the values may be preprocessed.

If you select option 2, questions GF-4 through GF-25 will be skipped.

Caution : Do not select Option 2 if a preprocess file from a previous simulation does not exist. Otherwise, a file error will occur when the module tries to find and read the file. Winds and boundary conditions may only be generated with the module when options 2 or 3 are selected, never with option 1.

GF-3 Question : **Enter the Sub-Grid Option >**

Options : 1 - Not a subgrid simulation.

2 - Subgrid simulation.

Preselect: None.

Define : If this is a subgrid simulation of an original SHALWV simulation, then enter a two (2). If this is not a subgrid simulation or if this is the original simulation prior to a subgrid simulation, then enter a one (1). (See discussion of subgrids in Part II).

Sometimes SHALWV is run to compute waves over a large area in order to determine wave information at certain coastal locations. To make SHALWV economical to run for such cases, the size of the computational grid cells is generally large. SHALWV, then, provides wave information at points that are far apart. If more detailed wave information is needed at a particular location in the grid, say the location of a coastal project, then a subgrid of the original larger grid is used to refine the wave information in the region of interest. (See Figure 7-6.) The SHALWV is then run for the subgrid using output information from the original grid as boundary conditions for the subgrid.

See question GF-27 for necessary specifications of input and output boundary conditions for the subgrid and original grid simulations.

Cautions : If the subgrid option is selected, then the General Input File from the original SHALWV simulation must exist. If it does not exist, an error will result. You may be unaware of the files that are being built and used by SHALWV, and therefore, you may not know whether the General Input File for the original SHALWV simulation exists. However, if you made the original SHALWV simulation prior to the subgrid simulation with no other simulations in between and you did not delete or remove any files from your directory, then the General Input File exists.

If this is a subgrid run, then the boundary conditions saved from the original grid must be interpolated using the INTERP program prior to running SHALWV. The program INTERP should be run upon completion of the General File Building routine.

PATH: o IF CALCULATING WAVES ONLY (Option 2, question GF-2), THEN GO TO GF-26

GF-4 Question : **Enter number of COLUMNS in Grid >**

Options : Range 3 - 100

Preselect: GF-2, option 1 or 3

Define : Figure 7-5 defines the columns of the computational grid.

Cautions : None.

GF-5 Question : **Enter number of ROWS in the Grid >**

Options : Range 3 - 100

Preselect: GF-2, option 1 or 3

Define : Figure 7-5 defines the rows of the computational grid.

Cautions : None.

PATH: o IF SUBGRID SIMULATION (Option 2, question GF-3), GO TO QUESTION GF-9

GF-6 Question : **Enter number of FREQUENCY BANDS >**

Options : Range 10 - 20

Preselect: GF-2, option 1 or 3; GF-3, option 1

Define : A wave energy spectrum is defined according to wave direction and frequency. An infinite number of frequency and direction bands is needed to define the wave energy spectrum. However, modeling an infinite number is not feasible. The energy is therefore grouped around discrete values of direction and frequency. You must select the number of frequency bands to define the wave energy spectrum.

Caution : A value of 20 frequency bands is recommended. A lower number of bands decreases the resolution of the wave energy spectrum, but also decreases the computation time for the simulation.

GF-7 Question : **Enter the number of DIRECTION BANDS >**

Options : Range 16 - 36

Preselect: GF-2, option 1 or 3; GF-3, option 1

Define : This is the same as question GS-6 except direction bands are stressed instead of frequency bands. The directional bands encompass a 360° arc. Therefore, selection of 16 direction bands produces direction band widths of 22.5°. (Note: the program will use the number of direction bands selected during computations. However, only 16 direction bands are used when data are written to output files).

Cautions : A value of 16 frequency bands is recommended for most simulations. A higher number of bands increases the resolution of the wave energy spectrum, but also increases the computation time for the simulation.

GF-8 Question : **Enter FREQUENCY BAND COMPUTATION OPTION >**

Options : 1 - frequency band values are computed.

2 - frequency band values are entered interactively.

Preselect: GF-2, option 1 or 3; GF-3, option 1

Define : You have the option to enter the frequency band values interactively or allow the computer to calculate the band values. If you request that the values be computed, you will be prompted (questions GF-15 and GF-16) for the initial frequency value and the frequency interval between bands.

The option to enter the frequency band values interactively allows you to input frequency values that are not separated by a constant frequency interval.

Caution : None.

GF-9 Question : **Enter WATER DEPTH INPUT OPTION >**

Options : 1 - Spatially constant water depth.

2 - Spatially variable water depth.

Preselect: GF-2, option 1 or 3

Define : The bathymetry of the model area may be specified either as constant or variable. If constant depth is selected, you will be prompted for the depth that is used for all points on the computational grid. If variable depth is selected, you will have the option to input the depth at every point on the computational grid either interactively or by specifying a file which contains the bathymetry information. If the data are supplied via a file, you will be prompted for the name of the file.

Cautions : None.

GF-10 Question : **Enter DEPTH CONVERSION FACTOR >**

Options : Variable.

Preselect: GF-2, option 1 or 3

Define : The depths that SHALWV uses must be in units of meters. Therefore, a conversion factor must be entered, allowing SHALWV to convert your depth information to meters. For example, if your input depths are given in feet, then a conversion factor of 0.3048 (m/ft) must be entered.

Cautions : If your bathymetry data are given in meters, then enter a value of 1.0 as a conversion factor.

GF-11 Question : **Enter DISTANCE BETWEEN GRID POINTS (km) >**

Options : > 0

Preselect: GF-2, option 1 or 3

Define : You must input the length (in kilometers) of the computational grid cells being used. The cells are assumed to be uniform and square.

Caution : Note that the size of the grid cells influences the size of the computational time-step allowed based on the Courant Stability Criterion (Equation 7-1 in Part II). The computational time-step is entered by question GF-13.

GF-12 Question : **Enter the REFRACTION SCALE FACTOR >**

Options : Range 1 - 100

Preselect: GF-2, option 1 or 3

Define : Represents the scale factor used to compute the refraction of the wave ray as shown in Figure 7-1 in Part II.

Caution : A refraction scale factor of 10 is recommended for accuracy and efficiency. A larger value will increase computation time and computer charges, while increasing accuracy.

GF-13 Question : **Enter COMPUTATIONAL TIME STEP (sec) >**

Options : > 0

Preselect: GF-2, option 1 or 3; GF-12

Define : The computational time-step is the amount of time in seconds between each computation. The value is related to the distance between grid points (question GF-11) and the greatest depth on the computational grid. The computational time step must be small enough to keep the modeling calculations stable. (See the discussion of the Courant Stability Criteria in Part II) From a physical point of view, the time-step should be smaller than the time it takes for the lowest frequency energy to propagate across the deepest grid cell.

If you do not know what time-step is satisfactory for your application, the following procedure can be used to determine an appropriate time-step. For arbitrary depths, calculate the group speed of the lowest spectral frequency (question GF-14 or GF-15) for deepwater conditions. Multiply by 1.2 and divide by the grid cell size (question GF-11) with dimensions converted to meters. The data summary produced at the end of the General File Building session will determine whether your selected time-step is valid. You will also be provided with the most efficient time-step that could be used. If your selected time-step is too high, you will be given an opportunity to change it. If your selected time-step is significantly lower than the provided time-step, you may consider increasing your selected value somewhat.

Cautions : Select a time-step that is some integer multiple of an hour (e.g. 60, 200, 1800, 3600 sec). This will facilitate selection of an output interval for SHALWV results. (See question GF-32 and GF-39.)

PATH:

- o **IF SUBGRID SIMULATION (Option 2, question GF-3) AND DEPTHS ARE VARIABLE (Option 2, question GF-9), GO TO GF-17.**
- o **IF SUBGRID SIMULATION AND DEPTHS ARE CONSTANT, GO TO GF-21.**
- o **IF FREQUENCIES BANDS ARE COMPUTED (Option 1, question GF-8), GO TO GF-15.**

GF-14 Question : **Enter the FREQUENCY BAND VALUES >**

Enter value #:

Options : > 0

Preselect: GF-2, option 1 or 3; GF-3, option 1; GF-6; GF-8, option 2

Define : The frequency band values are entered interactively, one value per line. Values for the number of frequency bands specified in Question GF-6 will be requested. The frequency va' =s do not have to have equal frequency intervals.

Cautions : Frequency values should be in units of Hertz (Hz). If the frequencies are not entered in ascending order, you will be asked to reenter the frequencies so that they are in ascending order.

The range of frequency values should span the range of frequencies that will contain significant wave energy. A reasonable range of values is from 0.25 to 4 times the peak frequency. For example, if wave conditions that are calculated by SHALWV are expected to have a peak period of 10 sec, then the peak frequency (inverse of the peak period) would be 0.1 Hz. Therefore, the frequencies band values should range between 0.025 and 0.4. Note that the lower the value of the first frequency band, the smaller the computational time-step must be, and the longer the simulation will take to complete.

PATH: o **IF FREQUENCY BAND VALUES ARE ENTERED INTERACTIVELY (Option 1, question GF-8), GO TO GF-17**

GF-15 Question : **Enter FIRST FREQUENCY band value >**

Options : > 0

Preselect: GF-2, option 1 or 3; GF-3, option 1; GF-8, option 1

Define : You must provide a starting frequency value to which the module will add frequency increments to derive all of the frequency band values. (The size of the frequency increment is specified in question GF-16.)

The range of frequency values should span the expected range of frequencies that contain significant wave energy. A reasonable range of values is from 0.25 to 4 times the peak frequency (inverse of the peak period). For example, if the largest wave conditions expected to be calculated by SHALWV have a peak period of 10 seconds, then the peak frequency would be 0.1 Hz. Therefore, the frequencies band values should range between 0.025 to 0.4. The first frequency band value is 0.025 Hz.

Cautions : First frequency value must be greater than zero. Note that the lower the value of the first frequency band, the smaller the computational time-step must be and longer the simulation will take to complete.

GF-16 Question : **Enter the FREQUENCY BAND INTERVAL >**

Options : > 0

Preselect: GF-2, option 1 or 3; GF-3, option 1; GF-6; GF-8, option 1

Define : You must provide the frequency increment value for computing the frequency band values. The increment value is cumulatively added to the first frequency value specified in question GF-15. The increment value must be such that when it is added to the first frequency value by the number of frequency bands specified in question GF-6, the resulting frequency band values will cover the necessary range of frequencies. For the example given in question GF-15, if there were 20 frequency bands specified in question GF-6, then the increment needed is about 0.02 Hz to get 20 equally spaced frequency bands between 0.025 to 0.4.

Cautions : None.

PATH: o **IF WATER DEPTHS ARE CONSTANT (Option 1, question GF-9), GO TO GF-21.**

GF-17 Question : **Are WATER DEPTHS in a file? (yes or no) >**

Options : y (Y) - yes, water depths are in a file.

n (N) - no, water depths will be entered interactively.

Preselect: GF-2, option 1 or 3; GF-9, option 2

Define : Water depths may be entered from a file, in which case you will be prompted for the file name, or they may be entered interactively, in which case you will be prompted for each depth value. Water depth values are required for each point in the computational grid. (Note: Although this question is asked only when you select option 2 in question GF-9, you may enter a constant water depth for every point on the computational grid. Option 1 in question GF-9 merely makes input of a constant water depth simple.)

Cautions : If you indicate that the water depths are in a file, you will be prompted for the name of the file. If you indicate that the water depths are not in a file, you will be expected to enter them interactively.

PATH: o IF **NO WATER DEPTH FILE (Option 'no', question GF-17), GO TO GF-19**

GF-18 Question : **Enter the WATER DEPTH FILE name >**

Options : Variable.

Preselect: GF-2, option 1 or 3; GF-9, option 2; GF-17, option "yes"

Define : The water depth file contains the water depth values for each point in the computational grid. The values must exist in the file in a "21F6.0" format (FORTRAN). If your grid has more than 21 points per row, then enter the first 21 points on one line of the data file, and the remaining points (up to 21) on the next line, and so on until all values for a row are entered. A new row begins a new line

in the data file. Figure 7-5 shows the orientation of the grid and the corresponding orientation of the water depth data. Water depths must be entered as positive numbers while land points are negative.

While building the water depth file, land should be identified by a depth value less than or equal to zero (0.0) to facilitate automatic generation of the Land/Water grid (question GF-22).

Cautions : The water depth file name must conform to the file naming conventions of the UNIX operating system (only the first 14 characters are significant). The units of the water depth data must be consistent with the conversion factor entered in question GF-10. The number of depth data values must be identical to the number of grid points (questions GF-4 and GF-5).

PATH: o IF WATER DEPTH FILE (Option 'yes', question GF-17), GO TO GF-22.

GF-19 Question : **Build the water depth file? (yes or no) >**

Options : y (or Y) = water depth values entered interactively.

n (or N) = water depth values not entered interactively.

Preselect: GF-2, option 1 or 3; GF-9, option 2; GF-17, option "no"

Define : Indicate whether you are ready to begin building the water depth file. If you indicate yes, the module will prompt you for water depth values for each point on the computational grid.

Cautions : If you indicate that the water depth file will not be built interactively, then the General File Building session will end and no information will be saved. You will be required to rerun the General File Building routine.

GF-20 Question : **Enter the WATER DEPTH MATRIX >**

Enter the value for ROW = ##, COL = ##:

Options : Variable.

Preselect: GF-2, option 1 or 3; GF-9, option 2; GF-17, option "no"; GF-19, option "yes".

Define : Begin entering the water depth values for the specified grid points. Figure 7-5 shows the orientation of the grid and the corresponding orientation of the water depth data. While building the water depth file, keep in mind that land should be identified by a value less than or equal to zero (0.0). This will facilitate automatic generation of the Land/Water matrix (question GF-22).

Cautions : The water depth values must be entered as positive numbers, and the units must be consistent with the depth conversion factor entered in question GF-10. You will not be given an opportunity to correct the depth data once you have entered them.

PATH: o **IF VARIABLE WATER DEPTHS (Option 2, question GF-9), GO TO GF-22.**

GF-21 Question : **Enter CONSTANT WATER DEPTH >**

Options : > 0

Preselect: GF-2, option 1 or 3; GF-9, option 1

Define : For applications where the depths can be assumed constant, entering a single water depth value for all points on the computational grid is possible. For example, in cases where all points are considered to be in deep water relative to the lowest frequency band value (see question GF-14 or GF-15), it may be convenient to enter a single, large depth value for all points of the grid (e.g. 9999 ft).

Cautions : The depth value must be consistent with the depth conversion factor entered in question GF-10.

GF-22 Question : **Enter the LAND/WATER MATRIX OPTION >**

Options : 1 - Enter the matrix interactively.

2 - Read the matrix from a file.

3 - Generate test matrix.

4 - Compute matrix from water depth file.

Preselect: GF-2, option 1 or 3

Define : The Land/Water matrix contains flags (ones (1) and zeros (0) to distinguish land (0) from water (1) on the computational grid. The orientation of the ones and zeroes, corresponding to points on the grid, must conform to the grid orientation identified in Figure 7-5.

If you elect to enter the matrix interactively, you will be prompted for a one (1) or zero (0) value for each point on the computational grid. If you elect to enter the matrix from a file, you will be prompted for the file name containing the matrix. The module checks for inconsistencies between the values for land/water points that you enter (interactively or by file) and the water depth information entered previously. The entered land/water values will be corrected to reflect the correct bathymetry information. That is, land points specified as a one (1) will be changed to a zero (0) and vice versa.

If you elect to use the test matrix, a matrix will be created containing all ones (1) except for zeroes (0) along the boundaries of the grid.

If you elect to let the module create the matrix from the water depth file, then the water depth values will be evaluated, and every grid point with a depth value less than or equal to zero (0.0) will be assigned a value of zero (0) and every point with a depth value greater than zero will be assigned a value of one (1). Also, zeroes (0) will be assigned to any point along the boundary of the grid.

Cautions : If you elect to enter the matrix from a file and the file does not exist or the values within the matrix are not in the proper format (see Part V), the General File Building session will end. No information will be saved. You must correct the file before rerunning the General File Building routine.

PATH:

- o **IF LAND/WATER MATRIX ENTERED INTERACTIVELY (Options 1, question GF-22), GO TO GF-25.**
- o **IF LAND/WATER TEST MATRIX DESIRED OR TEST (Option 3, question GF-22), GO TO GF-26.**
- o **IF LAND/WATER MATRIX IS GENERATED FROM BATHYMETRY DATA (Option 4, question GF-22), GO TO 26**

GF-23 Question : **Is there a LAND/WATER file? (yes or no) >**

Options : y (or Y) = file containing the Land/Water data exists.

n (or N) = Land/Water file does not exist.

Preselect: GF-2, option 1 or 3; GF-22, option 2

Define : If the Land/Water file exists, you will be prompted for the name of the file.

Cautions : If you answer yes and the file does not exist or the data are not formatted properly, or if you answer no, then the General File Building routine will end. No information will be saved. You will be required to rerun the General File Building routine from the beginning.

GF-24 Question : **Enter the LAND/WATER file name >**

Options : Variable.

Preselect: GF-2, option 1 or 3; GF-22, option 2; GF-23, option "yes"

Define : The Land/Water file name must be provided so that the module can read it to obtain the Land/Water matrix. If a satisfactory name is provided, the module reads the file. If the Land/Water file is read successfully, a message is issued indicating such. See Part V for a description of the required data format for the Land/Water File.

Cautions : If an error is encountered while the module reads the Land/Water File, then a message is issued indicating such and the General File Building session will end. No information will be saved, and you will be required to correct the Land/Water file and rerun the General File Building routine.

The Land/Water File name must conform to the file naming conventions of the UNIX operating system (only the first 14 characters are significant).

PATH: o **IF LAND/WATER MATRIX ENTERED FROM A FILE (Option 2, question GF-22), GO TO 26.**

GF-25 Question : **Enter the LAND/WATER matrix >**

Enter the value for ROW = ##, COL = ##:

Options : Variable.

2Preselect: GF-2, option 1 or 3; GF-22, option 1

Define : A one (1) or zero (0) must be entered for each point on the computational grid specified by the ROW and COLUMN values. A one indicates that the point is water, while a zero indicates that the point is land. The border of the grid must be labeled with zeroes.

Cautions : If the points on the border of the grid are not assigned values of zero, SHALWV will not run successfully.

PATH: o IF PREPROCESSING ONLY (Option 1, question GF-2), GO TO GF-53.

GF-26 Question : **Enter START-UP OPTIONS >**

Options : 1 - Cold start, no save.

2 - Warm start, no save.

3 - Cold start, save.

4 - Warm start, save.

Preselect: GF-2, option 2 or 3

Define : There are times when a series of related SHALWV simulations are required to perform a long simulation. For example, hindcasting wave conditions for a 10-year period could not be done with a single SHALWV simulation because the data that would be retained during the simulation would be too extensive for the computer to maintain. Instead, the hindcast would be conducted in short segments, each possibly 1 month long. To maintain consistency between each simulation, the wave conditions from the last computational period in one simulation would be used to initialize wave conditions for the next simulation. Such an initialization of a simulation is called a "warm start."

Option 1 indicates that no previous SHALWV simulation results will be used to initialize the current SHALWV simulation and no results will be saved for initializing any subsequent simulations. Option 2 indicates that the results from a previous SHALWV simulation will be used to initialize the current SHALWV simulation and that results will not be saved for initializing any subsequent simulations. Option 3 is the same as option 1 except that results from the current SHALWV simulation will be used to initialize a subsequent SHALWV simulation. Option 4 is the same as option 2 except that results from the current SHALWV simulation will be used to initialize a subsequent SHALWV simulation.

If you are going to run SHALWV several times using the output from one simulation to initialize the next simulation, then the first simulation would have option "Cold start, save" and the last simulation would have option "Warm start, no save." All of the simulations in between would use the option "Warm start, save."

Cautions : To use the warm start option, the results from a previous simulation have to be saved using the "Cold start, save" or "Warm start, save" option.

The wind and boundary condition data must overlap by one input time interval. That is, the last wind and boundary condition values entered in the previous simulation must be repeated as the first wind and boundary conditions in the next simulation.

GF-27 Question : **Enter BOUNDARY CONDITION OPTION >**

Options : 1 - No input or output boundary conditions.

2 - Output boundary condition information.

3 - Input boundary condition information.

4 - Input and output boundary information.

Preselect: GF-2, option 2 or 3

Define : Input Boundary and Initial Conditions.

When simulating wave conditions for a point on an open coast, the entire ocean basin may have to be modeled to determine the proper wave conditions that propagate into the region of interest from other regions during the simulation. To circumvent such limitations, input boundary conditions may be used that allow you to initialize the wave conditions over the entire computational grid at the start of the simulation and force input of wave energy spectra at the boundaries of the grid through the remainder of the simulation. (A special case where input boundary conditions are required is for subgrid simulations (question GF-3). See the discussion below regarding output boundary conditions for subgrids.)

The generation and transformation of input boundary data (input wave energy spectra) are conducted by the program BCGEN, which is discussed in Part IV. The BCGEN program must be run prior to SHALWV.

Initial conditions for the entire grid must also be specified with any input boundary condition specification. The initial conditions provide a means of prescribing a given sea state over the entire grid prior to the start of the simulation, which can greatly reduce the computational time required to bring the sea state up to the given condition. For example, assume a major weather system generates energy-based wave heights of about 7 m within a 5-hr period and 24 hr prior to the peak of the storm, waves in excess of 2 m existed, and 48 hr before that, the wave heights were approximately 0.5 m. You would want to start the simulation at the time of the 0.5-m wave conditions so that the model has sufficient time to generate a sea state similar to the actual sea state before the weather system of interest arrives. However, such a simulation would require a significant amount of computational time. A better way to model

the scenario would be to initialize the sea state to approximately 2.0 m at the start of the simulation. Very little computational time would be required to bring the simulated sea state to the level of the actual sea state.

Initial conditions are given by specifying the wave spectrum using the TMA spectral form (Bouws et al. 1984). The user must provide values for the five parameters that control the size and shape of the spectrum. The parameters are f_m, α, γ, σ_a, and σ_b, which are defined by:

$$E(f) = \frac{\alpha g^2}{2\pi} f^{-5} \exp\left[-1.25\left(\frac{f}{f_m}\right)^{-4}\right] \gamma \exp\left[\frac{-(f-f_m)^2}{2\sigma^2 f_m^2}\right] \phi(2\pi f, h)$$

where

g = gravitational acceleration

f = frequency band valve

f_m = peak spectral frequency band value

h = water depth

α = Phillip's Equilibrium Constant

γ = spectral peakedness factor

σ_a = spectral peak width to the low-frequency side

σ_b = spectral peak width to the high-frequency side

and ϕ is given by:

$$\phi(2\pi f, h) = [R(\omega_h)]^{-2} \left(1 + \frac{2\omega_h^2 R(\omega_h)}{\sinh[2\omega_h^2 R(\omega_h)]}\right)^{-1}$$

where

$$\omega_h = 2\pi f \left(\frac{h}{g}\right)^{\frac{1}{2}}$$

and $R(\omega_h)$ is found by iteration with:

$$R(\omega_h) \tanh\left[\omega_h^2 R(\omega_h)\right] = 1$$

The method recommended for selecting the parameters is as follows:

a. Let $\gamma = 3.3$, $\sigma_a = 0.07$, $\sigma_b = 0.09$, and f_m = the peak spectral frequency desired.

b. Iterate on values of α that provide the desired wave height condition (H_{mo}) given by:

$$H_{mo} = 4\sqrt{\int E(f)\, df}$$

If initial conditions are not desired, select a frequency value for f_m that is much larger than the peak frequency of the input boundary conditions.

Output Boundary Conditions.

If a subgrid simulation (question GF-3) will follow the current SHALWV simulation, then output boundary conditions must be saved from the current simulation to act as input boundary conditions for the subgrid simulation. (See Part II for a description of a subgrid simulation.) The output boundary conditions will be applied at points along the boundary of the subgrid. The boundary conditions will be interpolated and transformed over the subgrid by the INTERP program, which is discussed in Part IV. The INTERP program must be run prior to SHALWV.

Cautions : If the current simulation is a subgrid simulation (see question GF-3), then input boundary conditions must be specified using the output boundary conditions from the original SHALWV simulation. If you do not select either of the input boundary condition options (options 3 or 4), then the module will select it for you. That is, if you select option 1, it will be changed to option 3. If you select option 2, it will be changed to option 4. A message will be issued indicating a change has been made to your original selection.

Similarly, if the current simulation is the original large grid for a later subgrid simulation, then you must specify options 2 or 4. If you do not choose options 2 or 4, the module will not change your selection and you will not be able to conduct the later subgrid simulation.

GF-28 Question : **Enter the WIND INPUT OPTION >**

Options : 1 - Constant over time and space.

2 - Variable over time, constant over space.

3 - Variable over time and space.

Preselect: GF-2, option 2 or 3

Define : Constant winds are winds that do not vary in time or space during the simulation. One value is used for wind speed and one value for wind direction for the entire simulation. (If winds are not desired for the simulation, option 1 should be selected. Then, during the Wind File Building session, a constant wind speed value of 1 knot should be entered.)

The second wind data option requires winds that vary in time, but are constant in space. That is, for a given time, every point on the computational grid will have the same

wind speed and direction. This option makes entering wind conditions simple for simulations in which the water body is small enough that the winds can be considered the same at every point in the grid.

The third wind data option requires winds that are variable in time and space. That is, each point on the computational grid may experience winds that are different from winds experienced at other points at any given time.

Cautions : After the General File Building session is completed, a Wind File Building session MUST be conducted during which you will be prompted for wind speeds and directions based on whichever Wind Input Option you select. If you select option 1, you will be expected to enter the wind speed and direction interactively. If you select option 2, you will be expected to enter the wind speeds and directions for each wind input time-step (see question GF-33) either interactively or using a data file. If you select option 3, you will be expected to input the wind data through a data file only. The format of the wind data in the data files is discussed in Part V.

GF-29 Question : **Enter BOTTOM EFFECTS OPTION >**

Options : 1 - No bottom effects.

2 - Bottom effects.

Preselect: GF-2, option 2 or 3.

Define : SHALWV allows you to represent the effects of the sea bed on wave conditions during the simulation. If you select option 2, you will be prompted for the bottom friction coefficient and the bottom percolation factor.

Cautions : None.

PATH: o IF NO BOTTOM EFFECTS (Option 1, question GF-29), GO TO GF-32.

GF-30 Question : **Enter BOTTOM FRICTION COEFFICIENT >**

Options : $0.001 \leq \text{VALUE} \leq 0.015$

Preselect: GF-2, option 2 or 3; GF-29, option 2;

Define : The theoretical development of the bottom frictional energy loss mechanism was derived from work by Hasselmann and Collins (1968). They validated their approach using a bottom friction coefficient of 0.015 and based it on comparisons between field measurements and numerical results for a hurricane simulation. It is not clear that their value of 0.015 is accurate because they may have substantially overestimated the atmospheric input and required a large loss mechanism to compare more favorably to measurements. Experience with the bottom friction term in SHALWV is limited, but based on recent work and the approach used by Bouws and Komen (1983), the value for the bottom friction coefficient should be between 0.001 and 0.005.

Cautions : None.

GF-31 Question : **Enter BOTTOM PERCOLATION FACTOR (cm/sec) >**

Options : 0.0 < VALUE ≤ 2.0

Preselect: GF-2, option 2 or 3; GF-29, option 2;

Define : The formulation of the bottom percolation energy loss term comes directly from working Hsiao (1978), which was also published by Shemdin et al. (1980). From work conducted by Sleath (1970), the bottom percolation coefficients recommended are:

Coarse Sand	1.26	cm/sec
Fine Sand	0.145	cm/sec

Experience with the bottom percolation factor in SHALWV is limited. The amount of energy loss produced by the bottom percolation factor is uncertain.

Cautions : None.

GF-32 Question : **Enter NUMBER OF TIME STEPS between output >**

Options : > 0

Preselect: GF-2, option 2 or 3

Define : The results from SHALWV are provided at each time interval specified. The results include matrices of the wave characteristics (energy-based wave height, peak spectral period, and mean spectral propagation direction) for the entire grid, the wave characteristics (including those for the wind-sea portion of the spectrum, the swell portion of the spectrum and the total spectrum, as well as the wind speed and direction) and spectral energy values for specified grid locations (question GF-35). Descriptions and partial examples of output files are provided in Part V.

The model time-step size is specified in question GF-13. The interval used to output SHALWV results is based on the computational time-step. For example, if the computational time-step is 3 min (180 sec) and output results are desired at hourly intervals, then you would enter the value 20 for this question, that is, every 20 time-steps you want SHALWV results. (See question GF-36 for a discussion specifying output locations.)

Cautions : Note that the question does not ask for the amount of time between output intervals but the number of computational time-steps that occur between output intervals.

When specifying the computational time-step (question GF-13), it is recommended that the time-step be some integer factor or multiple of 1 hr (3,600 sec). That recommendation facilitates this question in that it allows easy specification of fractions or multiples of an hour for output of data.

Note that the smaller the interval used to output SHALWV results, the greater the volume of data that will be stored

in files. Also, the number of special output locations (question GF-35) influences the volume of data stored.

GF-33 Question : **Enter NUMBER OF HOURS BETWEEN INPUT WINDS >**

Options : > 0

Preselect: GF-2, option 2 or 3

Define : The wind data are required at integer multiples of an hour. For example, wind data are usually provided every hour, every 3 hr, or some other multiple of an hour. Generally, the wind input is provided at intervals greater than the computational time-step (question GF-13). Therefore, the wind input data are interpolated linearly by SHALWV to derive wind information for each computational time-step.

Cautions : If input boundary conditions are specified (question GF-27), they must be entered at the same interval as the wind data. If this is a subgrid simulation, the input boundary condition interval is specified as the BOUNDARY DATA OUTPUT INTERVAL (Question GF-37) in the original SHALWV simulation.

GF-34 Question : **Enter NUMBER OF WIND INPUT VALUES >**

Options : ≥ 2

Preselect: GF-2, option 2 or 3.

Define : The number of wind input values actually defines the length of the simulation. For example, if you select a wind input interval of 1 hr in question GF-33, then entering 24 for this question would mean that the simulation is for 24 hr. If the wind input interval was 3 hr, then entering 24 for this question would mean that the simulation is for 72 hr, and so on.

Cautions : None.

GF-35 Question : **Enter NUMBER OF SPECIAL OUTPUT LOCATIONS >**

Options : range 0 to 50

Preselect: GF-2, option 2 or 3.

Define : The output locations are those points on the computational grid at which output data should be saved by SHALWV to files. These output data are not the same as the output boundary condition data discussed in question GF-27. Description of the SHALWV results are provided in question GF-32 and Part V.

Cautions : If you select 0, SHALWV results will not be saved at any special locations. If you select a value between 1 and 50, you will be prompted for the ROW and COLumn values for the output locations (question GF-36).

PATH: o IF NO SPECIAL OUTPUT LOCATIONS (answer '0', question GF-35) AND THIS IS NOT A SUBGRID SIMULATION (Option 2, question GF-3) AND NO INPUT OR OUTPUT BOUNDARY CONDITIONS ARE SPECIFIED (Option 1, question GF-27), GO TO GF-53.

- o **IF NO SPECIAL OUTPUT LOCATIONS (answer '0', question GF-35) AND THIS IS A SUBGRID SIMULATION (Option 2, question GF-3), GO TO GF-37.**
- o **IF NO SPECIAL OUTPUT LOCATIONS (answer '0', question GF-35) AND INPUT BOUNDARY CONDITIONS SPECIFIED WITHOUT OUTPUT BOUNDARY CONDITIONS (Option 3, question GF-27), GO TO GF-44.**
- o **IF NO SPECIAL OUTPUT LOCATIONS (answer '0', question GF-35) AND OUTPUT BOUNDARY CONDITIONS SPECIFIED (Option 2 or 4, GF-27), GO TO GF-39.**

GF-36 Question : **Enter the OUTPUT LOCATIONS (COLUMN and ROW) >**
COLUMN and ROW for point ###:

Options : Variable.

Preselect: GF-2, option 2 or 3; GF-34, 0 < option ≤ 50.

Define : The column and row values must conform to the orientation of the grid as defined in Figure 7-5. If you enter the values incorrectly, you will be given an opportunity to correct them.

Cautions : Separate the entered values with a comma (,) or a space ( ). The module will not check whether the output location is a land or water point.

PATH:
- o **IF NOT A SUBGRID SIMUIATION (Option 1, question GF-3) AND NO INPUT OR OUTPUT BOUNDARY CONDITIONS SPECIFIED (Option 1, question GF-27), GO TO GF-53.**
- o **IF NOT A SUBGRID SIMULATION (Option 1, question GF-3) AND INPUT BOUNDARY CONDITIONS SPECIFIED WITHOUT OUTPUT BOUNDARY CONDITIONS (Option 3, question GF-27), GO TO GF-44.**
- o **IF NOT A SUBGRID SIMULATION (Option 1, question GF-3) AND OUTPUT BOUNDARY CONDITIONS SPECIFIED (Option 2 or 4, question GF-27), GO TO GF-39.**

GF-37 Question : **Enter the coordinates in the subgrid system that are associated with the following output boundary location from the original grid.**

The output location was at:

COLUMN = ## ROW = ##

Enter the corresponding subgrid coordinates >

Options : Variable.

Preselect: GF-2, option 2 or 3; GF-3, option 2; GF-27, option 3 or 4.

Define : The subgrid orientation must be coordinated with the original grid orientation as shown in Figure 7-6. This is accomplished by matching one of the output boundary condition points from the original grid with the corresponding point of the subgrid.

Cautions : None.

GF-38 Question : **Enter the SUBGRID INTERVAL >**

Options : > 1

Preselect: GF-2, option 2 or 3; GF-3, option 2; GF-27, option 3 or 4.

Define : To interpolate output boundary conditions from the original grid to points on the subgrid, the interval of the subgrid cells relative to the original grid cells must be identified. That is, if there are two subgrid rows and columns for each row and column of the original grid, then the subgrid interval is two (2). Similarly, if there are three subgrid rows and columns for each row and column of the original grid, then the subgrid interval is three (3).

After the correspondence between grid points is identified (question GF-37) and the subgrid interval is specified, then the Subgrid Interpolation File is automatically prepared for use by the INTERP program (see Part V). The INTERP program interpolates the output boundary condition data from the original grid to input boundary conditions for the subgrid simulation.

Cautions : None.

PATH: o **IF NO OUTPUT BOUNDARY CONDITIONS SPECIFIED (Option 1 or 3, question GF-27), GO TO GF-53.**

GF-39 Question : **Enter BOUNDARY DATA OUTPUT INTERVAL >**

Options : > 0

Preselect: GF-2, option 2 or 3; GF-27, option 2 or 4.

Define : The boundary output data are the data used as input for a subsequent subgrid simulation (question GF-3). Note that for any SHALWV simulation, the wind input interval and the input boundary condition interval must coincide. This means that the boundary data output interval for the original grid simulation must be the same interval as the input winds for the subgrid simulation. For example, if the computational time-step (question GF-13) is 3 min (180 sec) for the current (original) SHALWV simulation and the wind input interval for the subgrid simulation will be 1 hr (3,600 sec), then the boundary data output interval should be every 20 computational time-steps.

Cautions : Note that the question does not ask for the amount of time between output intervals but the number of computational time-steps between boundary data output.

GF-40 Question : **Enter the NUMBER OF OUTPUT LOCATIONS for subgrid >**

Options : > 0

Preselect: GF-2, option 2 or 3; GF-27, option 2 or 4.

Define : The number of locations on the original grid where output should be saved for a subsequent subgrid simulation must be identified. The output locations should include every grid point that is not designated as land along the borders of the subgrid. Note that since the outer edge of the subgrid will be designated as a solid boundary, the output locations should be one row or column inside the subgrid. (See Figure

7-6.) See questions GF-41, GF-42 and GF-43 for details about entering the COLUMN and ROW values for the locations.

If the number of locations is less than four (4), then you will be asked to input the COLUMN and ROW values for each location.

If four or more locations are specified, you will be asked to enter up to four locations, and the module will determine all of the locations (grid points) that lie between the locations you enter.

Cautions : None.

PATH: o **IF LESS THAN FOUR (4) OUTPUT BOUNDARY CONDITION LOCATIONS (question GF-40), GO TO GF-43.**

GF-41 Question : **Enter the first point location (COL & ROW) > COLUMN and ROW values:**

Options : Variable.

Preselect: GF-2, option 2 or 3; GF-27, option 2 or 4; GF-39, option 4.

Define : When four or more output boundary locations are used (question GF-40). You will be prompted for the COLUMN and ROW values for up to four (4) output locations. The locations you enter are the four points around the subgrid boundary as identified in the example in Figure 7-6. The module will determine which output boundary locations lie between the locations you enter.

Following the example in Figure 7-6, you will enter the values (31,16). Question GF-42 then asks for the remaining points in sequence, i.e., locations (26,16), (26,20) and (28,20). The module will then find all of the grid points that lie between these points, or locations (30,16), (29,16), (28,16), (27,16), (26,17), (26,18), (26,19), (27,20), and (28,20).

Cautions : None.

GF-42 Question : **Enter another point location (COL & ROW) > COLUMN and ROW values:**

Options : Variable.

Preselect: GF-2, option 2 or 3; GF-27, option 2 or 4; GF-40, option > 4.

Define : Following your entry of the first output boundary location in question GF-41, you must enter the next sequential point. (See description in question GF-41). If you have entered all of the corner points through previous repeats of this question, then enter a (0,0) to indicate that no more points will be entered.

Cautions : If you enter (0,0) when this question is first asked, the module will not have enough points with which to determine output boundary locations. The module will assume you no longer want to use output boundary locations, and it will

continue through the rest of the General File Building session. Any output boundary condition requests will be neglected. That is, no output boundary data will be saved for a subgrid simulation.

PATH: o **IF MORE THAN FOUR OUTPUT BOUNDARY CONDITION LOCATIONS (question GF-40) AND INPUT BOUNDARY CONDITIONS SPECIFIED (Option 3 or 4, question GF-27), GO TO GF-44.**

o **IF MORE THAN FOUR OUTPUT BOUNDARY CONDITION LOCATIONS (question GF-40) AND NO INPUT BOUNDARY CONDITIONS ARE SPECIFIED (Option 1 or 2, question GF-27), GO TO GF-53.**

GF-43 Question : **Enter the SUBGRID OUTPUT LOCATIONS > COLUMN and ROW for point ##:**

Options : Variable.

Preselect: GF-2, option 2 or 3; GF-27, option 2 or 4; GF-40, option 4.

Define : The column and row values for the number of locations specified in question GF-40 must be entered. Enter one pair of values (COL, ROW) per line. The output locations should correspond to locations along the border of the subgrid as shown in Figure 7-6.

Cautions : None.

PATH: o **IF NO INPUT BOUNDARY CONDITIONS (Option 3 or 4, question GF-27), GO TO GF-53.**

GF-44 Question : **Enter the NUMBER OF INPUT BOUNDARY LOCATIONS >**

Options : > 0

Preselect: GF-2, option 2 or 3; GF-3, option 1; GF-27, option 3 or 4.

Define : If you want to start your simulation with initial wave conditions, input boundary condition information is necessary. (See question GF-27, Input Boundary Conditions.) You may provide the input boundary conditions at locations which you specify on the border of the computational grid. If you indicate that fewer than four locations will be used to input boundary conditions, then you will be prompted for the COLUMN and ROW values for those locations.

If four or more locations are specified, you will be asked to enter up to four locations, and the module will determine all of the locations (grid points) that lie between the locations you enter.

Cautions : Note that this question is asked only for non-subgrid simulations. When subgrids are used, input boundary conditions can come only from previous SHALWV simulation where information was saved to act as input boundary location for a subsequent subgrid run#.

PATH: o **IF LESS THAN FOUR INPUT BOUNDARY CONDITION LOCATIONS (question GF-44), GO TO GF-47.**

GF-45 Question : **Enter the first point location (COL & ROW) > COLUMN and ROW values:**

Options : Variable.

Preselect: GF-2, option 2 or 3; GF-3, option 1; GF-27, option 3 cr 4; GF-44, option 4.

Define : When four or more input boundary locations are to be used (question GF-44), you will be prompted for the COLUMN and ROW values for up to four (4) input locations. The locations entered should be sequential, as shown in Figure 7-12. The module will determine which input boundary locations lie between the locations you enter. Note that the locations must be one row or column inside the grid because the outer boundary of the grid is assumed a solid boundary (land point in the Land/Water matrix).

Following the example in Figure 7-12, enter the value (10,1). Question GF-46 then asks for the remaining points in sequence, i.e., locations (10,4), (10,6) and (10,8). The module then finds all of the grid points that lie between these points, or locations (10,2), (10,3), (10,5) and (10,7).

Cautions : Land points specified as input boundary locations will provide no input to the model.

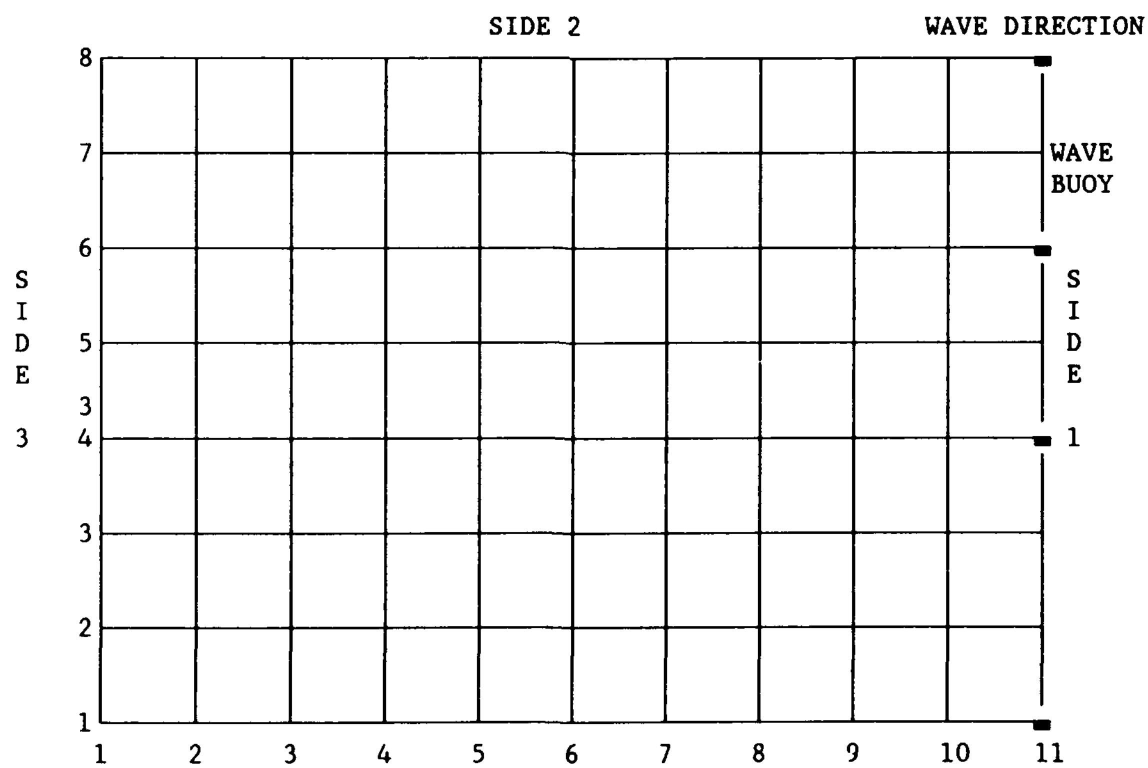


Figure 7-12. Example of input boundary condition location specifications

GF-46 Question : **Enter another point location (COL & ROW) > COLUMN and ROW values:**

Options : Variable.

Preselect: GF-2, option 2 or 3; GF-3, option 1; GF-27, option 3 or 4; GF-44, option > 4.

Define : Following your entry of the first input boundary location in question GF-45, you must enter the next sequential point. (See description in question GF-45.) When you have entered all of the points using this question, then enter a (0,0) to indicate that no more points will be entered.

Cautions : If you enter (0,0) when this question is first asked, the module will not have enough points with which to determine input boundary locations. The module will assume you no longer want to use input boundary locations, and it will continue through the rest of the General File Building session, neglecting any input boundary condition requests. The lack of input boundary conditions means that the simulation will begin without any initial wave conditions and no wave conditions will be propagated into the region being modeled from outside that region during the simulation.

Land points specified as input boundary locations will provide no input to the model.

PATH: o **IF FOUR OR MORE INPUT BOUNDARY LOCATIONS (question GF-44), GO TO GF-48.**

GF-47 Question : **Enter INPUT BOUNDARY LOCATIONS > COLUMN and ROW for point ##:**

Options : Variable.

Preselect: GF-2, option 2 or 3; GF-3, option 1; GF-27, option 3 or 4; GF-44, option ≤ 4.

Define : Enter the column and row values for the number of locations specified in question GF-44. Enter one pair of values (COL, ROW) per line. The input boundary locations should correspond to locations on the border of the grid as shown in Figure 7-12.

Cautions : Land points specified as input boundary locations will provide no input to the model.

GF-48 Question : **Enter the PEAK SPECTRAL FREQUENCY >**

Options : > 0

Preselect: GF-2, option 2 or 3; GF-3, option 1; GF-27, option 3 or 4

Define : (See the description of initial conditions in question GF-27.) The peak spectral frequency is based on the input boundary conditions. For example, if the wave used as a boundary condition has a 10-sec period, the peak spectral frequency would be the inverse of the period, or 0.1 Hz. If no initial conditions are desired, set the value to some

thing much larger than the peak frequency of the input boundary condition spectrum.

Cautions : None.

GF-49 Question : **Enter the Phillips' Equilibrium Constant >**

Options : $0 < VALUE \leq 0.1$

Preselect: GF-2, option 2 or 3; GF-3, option 1; GF-27, option 3 or 4;

Define : See description in GF-27. Note that selection of α may be used to control H_{mo}.

Cautions : None.

GF-50 Question : **Enter the Spectral Peakedness Factor >**

Options : $0 < VALUE \leq 4$

Preselect: GF-2, option 2 or 3; GF-3, option 1; GF-27, option 3 or 4

Define : See question GF-27 for description. A recommended value is 3.3.

Cautions : None.

GF-51 Question : **Enter the SPECTRAL PARAMETER, SIGMA A >**

Options : $0 < VALUE \leq 0.2$

Preselect: GF-2, option 2 or 3; GF-3, option 1; GF-27, option 3 or 4

Define : See question GS-27 for description. Recommended value is 0.07.

Cautions : None.

GF-52 Question : **Enter the SPECTRAL PARAMETER, SIGMA B >**

Options : $0 < VALUE \leq 0.2$

Preselect: GF-2, option 2 or 3; GF-3, option 1; GF-27, option 3 or 4

Define : See question GF-27 for description. Recommended value is 0.09.

Cautions : None.

GF-53 Question : **Enter the DIFFRACTION OPTION >**

Options : 1 - No diffraction

2 - Diffraction; data read from file

3 - Diffraction; data entered interactively

Preselect: GF-2, Option 2 or 3;

Define : See Part II for a description of the diffraction routines used in SHALWV. Indicate here whether diffraction will be used and, if so, how the diffraction information will be entered.

Cautions : None.

PATH: o IF NO DIFFRACTION (Option 1, question GF-53), GO TO GF-58.

o IF DIFFRACTION DATA ENTERED INTERACTIVELY (Option 3, question GF-53), GO TO GF-55.

GF-54 Question : **Enter the DIFFRACTION DATA FILE name >**

Options : Variable

Preselect: GF-2, option 2 or 3; GF-53, option 2

Define : You must identify the name of the file containing the diffraction data in order for SHALWV to use it. Once an acceptable file name is given, the module will read the diffraction file. If the diffraction data are read successfully, a message will be issued indicating such. If an error is encountered, a message will be issued indicating such and advising you that the diffraction option will be omitted from the simulation. If diffraction is still needed, the General File Building session must be terminated and the diffraction data file corrected. Then, the General File Building session must be rerun to include the diffraction option.

Cautions : If no satisfactory file name is entered, then the diffraction option will be omitted from the simulation. The General File Building session will proceed. The file name must conform to the file naming conventions of the UNIX operating system.

PATH: o IF DIFFRACTION DATA ENTERED BY A FILE (Option 2, question GF-53), GO TO 58.

GF-55 Question : **Enter the NUMBER OF DIFFRACTED LOCATIONS >**

Options : Variable.

Preselect: GF-2, option 2 or 3; GF-53, option 3

Define : A diffraction location is defined as the end of a breakwater (or island, etc.) around which diffraction will occur. The free field energy (unaffected by diffraction) used to calculate diffraction for the breakwater is the grid point opposite the end of the breakwater along the axis of the breakwater.

Cautions : You will be prompted for the column and row values for each diffracted location. If a zero (0) is entered, the module will assume that the diffraction option is no longer desired, and therefore, diffraction will be omitted from the simulation.

GF-56 Question : **Enter the Locations >**
COLUMN and ROW for point ##:

Options : Variable.

Preselect: GF-2, option 2 or 3; GF-53, option 3; GF-55, option > 0

Define : The column and row values (I,J locations) must be identified for each of diffracted locations indicated in question GF-

55. See Figure 5 for grid point orientation and numbering convention.

Cautions : None.

GF-57 Question : **Enter POSITION OPTION FOR THE DIFFRACTING STRUCTURE > Position number at point ## (col = ##, row = ##):**

Options : 1 - 8

Preselect: GF-2, option 2 or 3; GF-53, option 3; GF-55, option > 0

Define : The position of the diffracting structure pertains to the value of K. See question GF-55.

Cautions : None.

GF-58 Question : **Enter SHELTERING OPTION >**

Options : 1 = No Sheltering

2 = Sheltering; data read from file

3 = Sheltering; data entered interactively

Preselect: GF-2, Option 2 or 3;

Define : (See Part II). Sheltering allows you to manually reduce wave heights at desired grid locations. This is particularly useful in the lee of a solid structure such as an island or a breakwater where computed refraction and diffraction effects are not sufficient. If you elect to use sheltering, the required sheltering data may be entered from a file or interactively.

Cautions : If you elect the diffraction option in question GF-53, then sheltering must also be selected.

PATH:

- o IF NO SHELTERING (Option 1, question GF-58), BEGIN SUMMARY REVIEW.
- o IF SHELTERING DATA ENTERED INTERACTIVELY (Option 3, question GF-58), GO TO GF-60.

GF-59 Question : **Enter the SHELTERING DATA FILE name >**

Options : Variable.

Preselect: GF-2, option 2 or 3; GF-58, option 2

Define : You must identify the name of the file containing the sheltering data in order for SHALWV to use it. Once a suitable file name is given, the module will read the sheltering data file. If the sheltering data are read successfully, a message will be issued indicating such. If an error is encountered, a message will be issued indicating such and advising you that the sheltering option as well as the diffraction option will be omitted from the simulation. If sheltering and diffraction are still needed, the General File Building session must be terminated and the sheltering data file corrected. Then, the General File Building session must be rerun to include the sheltering option.

Cautions : **The file name must conform the file naming conventions of the UNIX operating system.**

GF-60 Question : **Enter the NUMBER OF SHELTERED LOCATIONS >**

Options : > 0

Preselect: GF-2, option 2 or 3; GF-58, option 3

Define : You must indicate how many locations on the computational grid require application of the sheltering option.

Cautions : If a zero (0) value is entered, the module will assume that sheltering is no longer desired and will omit it from the simulation. However, the diffraction option will also be omitted.

GF-61 Question : **Enter the Sheltered Locations >**
COLUMN and ROW for point ##:

Options : Variable

Preselect: GF-2. option 2 or 3; GF-58, option 3

Define : The column and row values must be entered for the number of sheltered points indicated in question GF-60.

Cautions : The locations must be over water. The module will not check to be sure locations are over water.

The grid points that you specify as sheltered will be displayed in a tabular format and you will then be given an opportunity to specify the "percent sheltered" for energy in each direction band, for each of the specified grid points.

37. At this point you will be presented with a summary review of the data that you entered during the General File Building session. You have the option to skip the summary if you so desire. You may want to look through the summary the first few times you run the General File Building session to acquaint yourself with the contents of it. However, the review can be lengthy. So once you have gained confidence in using the General File Building routine, you may prefer to skip the summary review.

Wind File Building routine

38. There are three modes in which winds may be entered in the SHALWV simulation. The first mode specifies winds as constant for the entire simulation period and area. For this mode, only one wind speed and direction are required. The second mode specifies temporally varying, spatially constant winds. For this mode, a wind speed and direction are entered for each wind input interval. The third mode specifies temporally and spatially varying wind speeds and directions. For this mode, wind speed and direction values are entered for each computational grid point and for each wind input

interval. The Wind File Building routine will create and format a Wind Data File for any of the above modes.

39. Wind input data should be equivalent over water, 10-m elevation, neuturally stable winds. Wind data obtained from meteorological stations may not fit these criteria. However, most data can be corrected to be approximately "equivalent" to the above criteria. Methods for correcting wind data can be found in the *Shore Protection Manual* (SPM 1984). Note that winds are required for any SHALWV simulation. If winds are not desired, values of 1 knot should be used for wind speed.

40. The wind data for the constant wind input mode can be entered interactively only during the Wind File Building routine. The wind data for temporally varying wind input mode may be entered either interactively during the Wind File Building session or through a data file that contains the wind information. The wind data for the temporally and spatially varying wind input mode must be entered via a file. It is assumed that the volume of data for this mode is too great to be entered interactively. Descriptions of the required formats for files containing the temporally varying only or the temporally and spatially varying wind data are given in Part V.

41. It is recommended that the General Input File Building routine be run prior to running the Wind Input File Building routine. The selection of the wind input mode and other options required for wind input is made during the General File Building session. The Wind Input File Building routine reads the General Input File to obtain that information and then prompts the user for the proper wind information. If the Wind File Building Routine is run before the General File Building Routine, then the user will be asked by the Wind File Building routine to specify the wind input mode and other options. The user must then be sure that the same specifications are made when the General File Building routine is used. Note that if the specifications are not identical between the two file building routines, an error will result when SHALWV is run. The Wind Input File Building routine is the only routine in the SHALWV branch of the Spectral Wave Modeling Module that can be executed without previously running the General File Building routine.

Data descriptions for Wind Input File

42. Descriptions of the data prompted for by the module during the Wind Input File session are provided below. The format used to describe the data is the same as that discussed in Part IV.

WF-1 Question : **General File Building has been run? (yes/no) >**

Options : y (or Y) - General File Building routine has been run

n (or N) - General File Building routine was not run

Preselect: None.

Define : See introductory description to this section of the User's Guide.

Cautions : If you answer yes, you must be certain that the General Input File exists. If it does not exist, an error will occur, and the Wind File Building session will end. If you answer no, you must be certain that the values you provide for questions WF-2, WF-3, WF-4, WF-14, and WF-15 are respectively identical to your answers to questions GF-28, GF-33, GF-34, GF-4 and GF-5 in Part IV.

PATH: o IF GENERAL FILE BUILDING ROUTINE HAS BEEN RUN (Option 'yes', question WF-1), GO TO GF-5.

WF-2 Question : **Enter Wind Field Type >**

Options : 1 - Constant winds

2 - Constant over space, variable over time

3 - Variable over space and time

Preselect: WF-1, option "no"

Define : The wind input mode must be defined. For simulations where wind speed and direction are considered constant over space and time, it is convenient to use option 1 to minimize the amount of data entered. You will be prompted for one pair of wind speed and direction values.

For simulations where winds vary over time but not over space (e.g., a small body of water where winds are virtually the same everywhere), then option 2 should be selected. The data may be entered via a data file or interactively. If the winds vary in time and space, then option 3 must be selected. The volume of data for winds that vary over time and space is usually so large that it can be entered only via a data file. (The formats for the wind data files can be found in Part V.)

Cautions : The mode selected must be consistent with the mode selected for question GF-28 in Part IV. The wind data must be given as the equivalent, overwater 10-m elevation, neutrally stable winds.

WF-3 Question : **Enter No. hours between wind inputs >**

Options : Must be between 1 and 24 (inclusive).

Preselect: WF-1, option "no"

Define : The wind data must be input at regular intervals during the simulation (e.g. every hour (1), every 2 hours (2), etc.). The interval between wind inputs, together with the answer

to WF-4 (number of wind input intervals) define the length of the simulation. For example, if the interval is every 2 hr and there are 12 wind input intervals, then the simulation is for a 24-hr period (2 hr times 12).

Cautions : The value selected must be consistent with the value selected for question GF-33 in Part IV.

WF-4 Question : **Enter the total number of wind inputs >**

Options : 1 ≤ VALUE < 100

Preselect: WF-1, option "no"

Define : The total number of wind inputs and the number of wind input intervals implicitly define the length of the simulation. That is, based on the size of the time interval between wind inputs (WF-3) and the number of intervals, the total length of the simulation is defined. For example, if the time interval is 2 hr and the number of intervals is 12, then the simulation is for 24 hr (2 hr times 12).

Cautions : The value selected must be consistent with the value selected for question GF-34 in Part IV.

WF-5 Question : **Enter Wind Speed Convention >**

Options : 1 - Meters per second

2 - Miles per hour

3 - Knots

Preselect: None.

Define : The units for the wind speed must be defined. The units are converted automatically to knots for use by SHALWV.

Cautions : None.

WF-6 Question : **Enter direction convention for winds >**

Options : 1 - Cartesian, "TOWARD which winds blow."

2 - Meteorological (° azimuth), "FROM which winds blow."

Preselect: None.

Define : The convention used to define the wind direction must be provided. The convention will be converted to Cartesian automatically for use by SHALWV. See Figure 7-13 for an illustration of the different conventions.

Cautions : None.

PATH:

- **IF WINDS ARE SPATIALLY CONSTANT AND TEMPORALLY VARYING (Option 2, question WF-2), GO TO WF-9.**
- **IF GENERAL FILE BUILDING ROUTINE WAS NOT RUN (Option 'no', question WF-1) AND WINDS ARE SPATIALLY AND TEMPORALLY VARYING (Option 3, question WF-2), GO TO WF-14.**
- **IF GENERAL FILE BUILDING ROUTINE WAS RUN (Option 'yes', question WF-1) AND WINDS ARE SPATIALLY AND TEMPORALLY VARYING (Option 3, question WF-2), GO TO WF-16.**

WF-7 Question : **Enter the wind speed >**

Options : 0 < VALUE < 100

Preselect: WF-2, option 1

Define : The wind speed (assumed constant over space and time) must be entered in the units specified in question WF-5. Note that SHALWV rounds the numbers to integer values, so be sure that the value is sufficient so as not to round to zero.

Cautions : The wind data must be given as the equivalent, 10-m elevation, neutrally stable winds. Although SHALWV is designed to simulate hurricane-generated wave conditions, there has been an upper limit set on the maximum wind speed. If you require greater wind speeds than allowed, contact CERC for support.

WF-8 Question : **Enter the Wind Direction >**

Options : 0 ≤ VALUE < 360 degrees

Preselect: WF-2, option 1

Define : The wind direction (assumed constant over space and time) must be entered using the direction convention specified in question WF-6.

Cautions : The winds must be given as the 10-m elevation, neutrally stable overwater values.

PATH: o **END WIND FILE BUILDING ROUTINE**

WF-9 Question : **Input Wind Information from a File? (yes/no) >**

Options : y (or Y) - Wind data will be entered from a file

n (or N) - Wind data will be entered interactively

Preselect: WF-2, option 2

Define : You may enter the wind speed and direction for every wind input interval (see question WF-4 and GF-34 in Part IV) interactively or by a data file. If the data will be entered by a file, the file must currently exist. The data format for the file is described in Part V.

Cautions : If you answer yes and the file does not exist or there is an error in the data format within the file, an error message will be issued and the Wind File Building session will end. No information will be saved, and you will be required to correct the file format before rerunning Wind Input File Building routine.

PATH: o **IF WIND DATA ENTERED INTERACTIVELY (Option 'no', question WF-9), GO TO WF-12.**

WF-10 Question : **Enter the Input Wind File Name >**

Options : Variable

Preselect: WF-2, option 2; WF-9, option "yes"

Define : The name of the file containing the wind speeds and directions must be identified.

Cautions : The file name must conform to the file naming conventions of the UNIX operating system. If the file cannot be found, the Wind File Building session will end. No information will be saved. You will be required to correct the file and rerun the Wind Input File Building routine.

WF-11 Question : **Does File Contain Dates? (yes or no) >**

Options : y (or Y) = the file does contain date headers

n (or N) = the file does not contain date headers

Preselect: WF-2, option 2; WF-9, option "yes"

Define : You have the option to include date headers in the wind data file that is read by the module. (See data format description in Part V.) You must specify whether date headers have been included in your wind data file.

Cautions : If you provide the incorrect specification of the date headers, an error will occur when the module tries to read the wind data. A message will be issued indicating such, and the Wind File Building session will be terminated. No information will be saved. You must correct the file format before the Wind Input File Building routine can be rerun.

PATH: o IF WIND FILE CONTAINS DATES (Option 'yes', question WF-11), END WIND FILE BUILDING ROUTINE.

WF-12 Question : **Enter the start date for wind input >**

Options : $0 \leq \text{VALUE} \leq 99999999$

Preselect: WF-2, option 2; WF-9, option "no"

Define : The date corresponding to the first set of wind speed and direction values must be entered. The format used is 'yymmddhh' where yy is the year, mm is the month, dd is the day, and hh is the hour (military time, e.g., 00 = midnight and 23 = 11 pm). The dates that correspond to the other data values will be automatically generated. The dates are incremented by the interval identified in question WF-3 or question GF-33 in Part IV.

Cautions : None.

WF-13 Question : **Wind Speed and Direction:**

Options : $0 < \text{Wind Speed} < 100$

$0 \leq \text{Wind Direction} < 360$

Preselect: WF-2, option 2; WF-9, option "no"

Define : The pairs of wind speed and direction data must be entered sequentially for each wind input interval (question WF-4 and question GF-34 in Part IV). The values should be separated by a comma (,) or a space ( ).

Cautions : None.

PATH: o END WIND FILE BUILDING ROUTINE.

WF-14 Question : **Enter Number of Columns in Grid >**

Options : 5 to 100

Preselect: WF-1, option "no"; WF-2, option 3

Define : See description for question GF-4 in Part IV.

Cautions : The selected value must be consistent with the value entered for question GF-4 in Part IV.

WF-15 Question : **Enter the Number of Rows in the Grid >**

Options : 5 to 100

Preselect: WF-1, option "no"; WF-2, option 3

Define : See description for question GF-5 in Part IV.

Cautions : The value selected must be consistent with the value entered for question GF-5 in Part IV.

WF-16 Question : **Select Coordinate System >**

Options : 1 = Cartesian

2 = User-defined coordinate system

Preselect: WF-2, option 3

Define : You must define the coordinate system that you are using for your computational grid. Examples of each coordinate system are shown in Figure 7-13. Both computational grids have the same number of grid points; they are simply numbered differently. The Cartesian coordinate system is used by SHALWV. If you are using a user-defined coordinate system, then the information you enter will be transformed to a Cartesian coordinate system by the module.

The user-defined coordinate system uses distances to identify each grid point. This system is useful when interpolation of meteorological data from buoys is to be performed to acquire wind information at all grid locations. That is, the exact location of the buoys based on the user-defined grid may be used, rather than the location of the nearest Cartesian grid point. From that exact location, wind information can be interpolated to the grid points on a Cartesian grid which will be used by SHALWV.

If you select the user-defined coordinate system, then you will be asked for the coordinates of the corners of your grid to facilitate transformation of your grid to a Cartesian system.

Cautions : None.

PATH: o IF CARTESIAN COORDINATE SYSTEM BEING USED (Option 1, question WF-16), GO TO WF-25.

WF-17 Question : **Enter X coordinate of the lower left corner of the grid >**

Options : ≥ 0

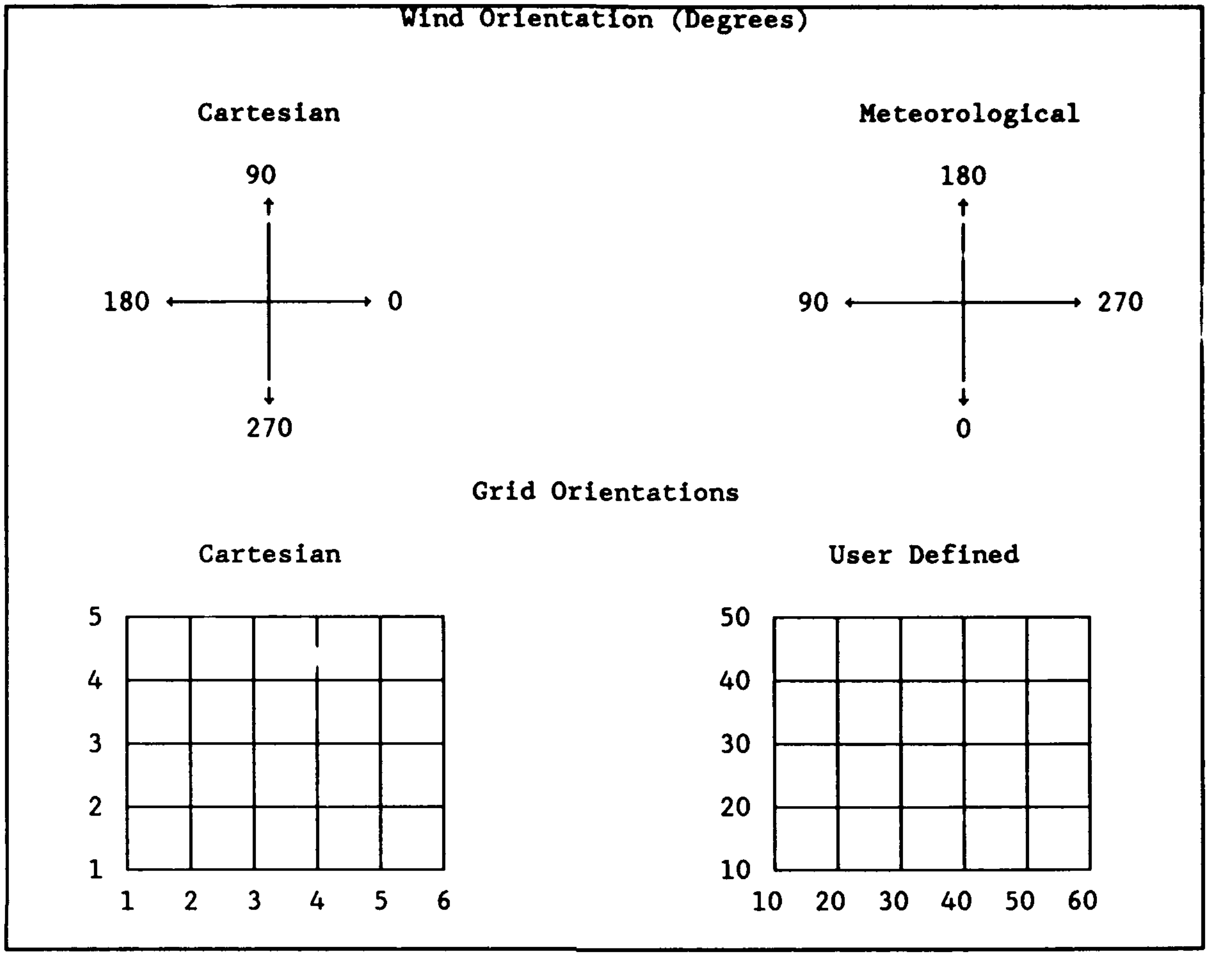


Figure 7-13. Grid coordinate conventions for entry of wind information.

Preselect: WF-2, option 3; WF-16, option 2

Define : The x-coordinate (in the user-defined system) for the lower left-hand corner of your computational grid must be entered. See Figure 7-13 for an example.

Cautions : None.

WF-18 Question : **Enter Y coordinate of the lower left corner of the grid >**

Options : ≥ 0

Preselect: WF-2, option 3; WF-16, option 2

Define : The y-coordinate (in the user-defined system) for the lower left-hand corner of your computational grid must be entered. See Figure 7-13 for an example.

Cautions : None.

WF-19 Question : **Enter X coordinate of the upper right corner of the grid >**

Options : > 0

Preselect: WF-2, option 3; WF-16, option 2

	Define :	The x-coordinate (in the user-defined system) for the upper right-hand corner of your computational grid must be entered. See Figure 7-13 for an example.
	Cautions :	None.
WF-20	Question :	**Enter Y coordinate of the upper right corner of the grid >**
	Options :	> 0
	Preselect:	WF-2, option 3; WF-16, option 2
	Define :	The y-coordinate (in the user-defined system) for the upper right-hand corner of your computational grid must be entered. See Figure 7-13 for an example.
	Cautions :	None.

PATH: o GO TO WF-25. (Questions WF-21 through WF-24 are not currently in use.)

WF-21	Question :	**Enter X coordinate of the upper left corner of the grid >**
	Options :	> 0
	Preselect:	WF-2, option 3; WF-16, option 2
	Define :	The x-coordinate (in the user-defined system) of the upper right-hand corner of your computational grid must be entered. See Figure 7-13 for an example. Based on the corner coordinates entered in questions WF-17 through WF-20, the module can determine the orientation of the grid.
	Cautions :	None.
WF-22	Question :	**Enter Y coordinate of the upper left corner of the grid >**
	Options :	>0
	Preselect:	WF-2, option 3; WF-16, option 2.
	Define :	This question is asked only if your grid is rotated from a true NORTH-SOUTH, EAST-WEST orientation. The y-coordinate (in the user-defined system) for the upper left-hand corner of your computational grid must be entered. See Figure 7-13 for an example.
	Cautions :	None.
WF-23	Question :	**Enter X coordinate of the lower right corner of the grid >**
	Options :	≥ 0
	Preselect:	WF-2, option 3; WF-16, option 2.
	Define :	This question is asked only if your grid is rotated from a true NORTH-SOUTH, EAST-WEST orientation. The x-coordinate (in the user-defined system) for the lower right-hand corner of your computational grid must be entered. See Figure 7-13 for an example.
	Cautions :	None.

WF-24 Question : **Enter Y coordinate of the lower right corner of the grid >**

Options : ≥ 0

Preselect: WF-2, option 3; WF-16, option 2.

Define : This question is asked only if your grid is rotated from a true NORTH-SOUTH, EAST-WEST orientation. The y-coordinate (in the user-defined system) for the lower right-hand corner of your computational grid must be entered. See Figure 7-13 for an example.

Cautions : None.

WF-25 Question : **Enter thϵ Input Wind File Name >**

Options : Variable

Preselect: WF-2, option 3.

Define : The module assumes that the wind information will be input from a file because of the volume of data required for a spatially and temporally varying wind field is extensive.

Cautions : The file name must conform to the file naming conventions of the UNIX operating system. If the file name is incorrect, the Wind File Building session will end. No information will be saved. The Wind Input File Building routine must be rerun.

WF-26 Question : **Enter Data Format Option >**

Options : 1 - data is in SHALWV format

2 - data is in Meteorological Station format

Preselect: WF-2, option 3.

Define : There are two types of wind data file formats that are defined in Part V. If the data are in an accepted format for SHALWV, then the file will be read to check the format for errors. If the data are in Meteorological Station format, the data will be read for each meteorological station and then interpolated to every point on the computational grid. The influence of meteorological station data on particular points on the computational grid will be determined by each station proximity to the particular point of interest.

Cautions : None.

PATH: o END WIND FILE BUILDING ROUTINE

<u>Bounday Condition File Building routine</u>

43. The development of wave conditions in a given location, particularly an open coastal location, usually depends on two forcing factors--the wind and the waves propagating in from other locations. Hence, any accurate simulation of wave development at a given location must consider these

factors. The wind input for a SHALWV simulation is discussed in Part IV. The input of wave conditions propagating from other locations is discussed below.

44. The input boundary condition option in SHALWV provides the user with a technique for representing wave conditions that are propagating into the region that is being simulated, i.e., energy derived from storm conditions from somewhere outside the bounds of the computational grid. The Boundary Condition File-Building routine allows the a user to specify the type of input boundary conditions (and corresponding initial conditions as described in question GF-27) for a given SHALWV simulation. The utility of this option is shown in the following example. If a user wants to simulate the wave conditions for a certain coastal location, the entire oceanic basin might have to be modeled to ensure that the waves propagating into the coastal region of interest from other parts of the ocean basin are known. Then, to refine the calculation of wave conditions at the point of interest, additional SHALWV subgrid simulations (Part II) would be required. The disadvantage is that the computational time required to model the entire basin and any additional subgrids would be expensive. To alleviate the need for modeling an entire ocean basin and one or more subgrids, input boundary conditions may be used. For example, if a directional wave monitoring buoy was positioned near the region of interest, the wave information from that buoy could be used to represent the energy propagating in from other parts of the ocean basin. Hence, a single, fine-resolution grid could be used around the region of interest, saving computational time.

45. Input boundary conditions may be specified in several ways. They may be specified as unchanging throughout the simulation (constant), or they may be specified as variable over time. They may be specified by simple wave characteristics like the energy-based wave height, peak spectral period, and mean spectral propagation direction, or by spectrally based parameters like peak spectral frequency, Phillip's Equilibrium constant, and the spectral peakedness and width factors. Actual one- and two-dimensional spectra, like that which is measured by wave buoys, may be specified, too. If constant input boundary conditions are specified, the wave condition descriptors (height, period, spectral parameters, etc.) that the user provides will be used through the entire simulation. If time-varying input boundary conditions are specified, then the user must provide the wave condition descriptors for

every input interval. The input interval must be equivalent to the wind input interval (specified in question GF-33 in Part IV or WF-3 in Part IV).

46. The input boundary condition information that is provided by the user is input along the borders of the computational grid. The user may select the borders (sides) to which the input boundary conditions may be applied. They will always be applied to the side of the grid through which the spectrum is primarily propagating (the input side). The input boundary condition information that is provided by the user is given for a specified water depth. The boundary condition program BCGEN assumes that the specified depth is the same at every point along the input side of the grid. (This is usually a reasonable approximation.) The specified boundary conditions are then applied to every point along the input side of the grid. The user may also specify whether to input boundary conditions along one or both of the grid sides to the left or right of the input side of the grid. The input boundary condition information is transformed based on depth to all grid points along the left and/or right sides of the grid.

47. The descriptions that follow outline the questions with which the module prompts the user to gather information for generating the input boundary conditions. The module will place the information in a file, and then the boundary condition program BCGEN must be run to transform the boundary conditions to the specified grid points.

Input Descriptions

BC-1 Question : General File Building has been run? (yes or no) >

Options : y (or Y) = General File Building routine has been run
n (or N) = General File Building routine not run

Preselect: None.

Define : Some of the files generated by the General File Building routine must exist prior to using the Boundary Condition File Building routine.

Cautions : If the General File Building routine has not been run and yet you answer yes, an error will occur when the Boundary Condition File Building routine searches for the existence of the General File Building routine's files.

PATH: o **IF GENERAL FILE BUILDING ROUTINE HAS NOT BEEN RUN (Option 'no', question BC-1), END THE BOUNDARY CONDITION FILE BUILDING ROUTINE.**

BC-2 Question : **Enter TIME VARIATION OPTIONS >**

Options : **1 - Constant wave/spectra over time**

2 - Variable wave/spectra over time

Preselect: None.

Define : The input boundary conditions may be specified as either time-varying or time-invariant. If time-varying boundary conditions are selected, you will be prompted for boundary conditions for every input interval of the simulation. The input interval is the same as the wind input interval specified in question GF-33 in Part IV. If time-invariant boundary conditions are selected, you will be prompted for a single set of boundary condition data that will be used for the entire simulation period.

Cautions : None.

BC-3 Question : **Enter *BOUNDARY CONDITION* OPTION >**

Options : 1 - Input wave characteristics

2 - Input spectral characteristics

3 - Input one-dimensional frequency spectrum

4 - Input two-dimentional frequency-direction spectrum

Preselect: None.

Define : You must specify the type of boundary conditions you will be based providing. Option 1 will require you to enter energy wave heights, periods, and directions as boundary conditions. Option 2 will require you to enter the peak spectral frequency, Phillip's Equilibrium constant, spectral peakedness factor, and the spectral peak-width factors. Options 3 and 4 will require you to enter either the one- or two-dimensional spectrum as appropriate.

Cautions : None.

PATH:
- o IF ONE-DIMENSIONAL SPECTRUM IS ENTERED (Option 3, question BC-3), GO TO BC-5.
- o IF TWO-DIMENSIONAL SPECTRUM IS ENTERED (Option 4, question BC-3), GO TO BC-9.

BC-4 Question : **Enter FREQUENCY SPECTRAL SHAPE OPTION >**

Options : 1 - Kittigoradski, deep and shallow

2 - Pierson-Moskowitz, deep only

3 - JONSWAP, deepwater with mean values

4 - JONSWAP/TMA, computed alpha and gamma

Preselect: BC-3, options 1 or 2;

Define : When the input boundary conditions will not be given as an explicit spectrum (i.e. one- or two-dimensional spectrum), then you must specify the type of spectrum that should be generated based on the wave or spectral characteristics you

will be entering later. The boundary condition program BCGEN (see Part IV) converts the wave and spectral characteristics into a one-dimensional spectrum based on the frequency shape factor selected here. Option 4 is recommended.

Cautions : None.

BC-5 Question : **Enter DIRECTION DISTRIBUTION SHAPE OPTION >**

Options : 1 = $\cos^{nn}\theta$

2 = $\cos^{2p}(\frac{\theta}{2})$

Preselect: BC-3, option 1, 2, or 3;

Define : As with the frequency shape factor discussed in question BC-4, the shape of the spread of the spectrum across the direction domain must be specified. You will be asked later to enter the value for 'nn' or possibly 'p' depending on the option that is selected. The shape of the directional spreading will be applied to any type of input boundary condition to generate a two-dimensional spectrum except when an explicit two-dimensional spectrum is entered.

Option 1 is a simplified cosine power expression, whereas Option 2 is derived from the work of Mitsuyasu (1981). You will be given the option to enter the value of 'p' in option 2 interactively during this Boundary Condition File Building routine, or to have it computed by the module.

Cautions : None.

PATH: o IF $\cos^{2p}(\theta/2)$ SPREADING FUNCTION SELECTED (Option 2, question BC-5), GO TO BC-7.

BC-6 Question : **Enter SPECTRAL SPREADING FUNCTION EXPONENT >**

Options : Variable.

Preselect: BC-3, options 1, 2, or 3; BC-5, option 1.

Define : The spreading function exponent is the value of nn in the expression $\cos^{nn}$. A low value of nn (2, 3, etc.) will provide a wide spread in direction about the principal propagation direction of the spectrum. Higher values for nn (40, 200, 1000, etc.) provide a spectrum with decreasing directional spread. In general, a value of 4 may be used for a sea-wave spectrum, and a value of 8 for a swell-wave spectrum.

Cautions : None.

PATH: o IF $\cos^{nn}\theta$ SPREADING FUNCTION SELECTED (Option 1, question BC-5), GO TO BC-9.

BC-7 Question : **Enter 'p' COMPUTATION OPTION >**

Options : 1 = 'p' value computed

2 = 'p' value entered interactively

Preselect: BC-3, option 1, 2, or 3; BC-5, option 2.

Define : The value for p in the term $\cos^{2p}(\theta/2)$ may be entered interactively or it may be computed by the module. The derivation of p is based on the work of Mitsuyasu (1981).

Cautions : None.

PATH: o IF 'p' VALUE IS COMPUTED (Option 1, question BC-7), GO TO BC-9.

BC-8 Question : **Enter SPREAD PARAMETER >**

Options : Variable.

Preselect: BC-3, options 1, 2, 3; BC-5, option 2; BC-7, option 2;

Define : A low value for p will provide a spectrum with a large directional distribution about the principal direction of propagation. A high value for p will provide a spectrum with a small directional distribution about the principal direction of propagation. Recommended values are 8 for a sea-wave spectrum or 16 for a swell spectrum.

Cautions : None.

BC-9 Question : **Enter GRID SIDE from which waves are coming >**

Options : 1, 2, 3, or 4

Preselect: None.

Define : The sides of the grid are defined in Figure 7-12. For the example wave direction given in the figure, you would choose side 1 because the waves are primarily propagating through this side, although they also propagate through side 2.

Cautions : None.

BC-10 Question : **Enter GRID SIDE TRANSFORMATION OPTION >**

Options : 1 = No sides are transformed

2 = One side, left of input side is transformed

3 = One side, right of input side is transformed

4 = Two sides, left and right sides are transformed

Preselect: None.

Define : Besides specifying the primary side of the grid for input boundary conditions, other sides of the grid may be specified. When another side(s) is specified, the wave characteristics of the boundary conditions specified for the input side are transformed (refracted and shoaled) to the specified side(s) based on the bathymetry provided during the General File Building routine (Part IV). In the example in Figure 7-12, you would select side 2 or the "right side" of the input side (side 1) for entering boundary conditions because the waves pass through this side somewhat even though they primarily pass through side 1.

Cautions : None.

BC-11 Question : **Enter the Start date for spectral input >**

Options : $0 \leq \text{VALUE} \leq 99999999$

Preselect: None.

Define : The date for the first input boundary condition must be specified. The module automatically computes the dates for the remaining input boundary condition data based on the input interval (equivalent to the wind input interval specified in question GF-33 in Part IV).

Cautions : The value should be consistent with the date for the first wind input data (question WF-12, Part IV).

PATH:

- **IF SPECTRAL WAVE CHARACTERISTICS ARE ENTERED (Option 2, question BC-3), GO TO BC-17.**
- **IF ONE-DIMENSIONAL SPECTRAL DATA ARE ENTERED (Option 3, question BC-3), GO TO BC-25.**
- **IF TWO-DIMENSIONAL SPECTRAL DATA ARE ENTERED (Option 4, question BC-3), GO TO BC-31.**

BC-12 Question : **Enter WAVE TYPE OPTION >**

Options : 1 - Wind sea conditions

2 - Swell conditions

Preselect: BC-3, option 1.

Define : SHALWV simulates both sea and swell created by winds in a two-dimensional spectrum, transforming them using different methods. Therefore, you must identify whether the input boundary conditions that you are entering are locally generated wind-sea or swell. The boundary condition program BCGEN will convert the wave characteristics that you enter into a two-dimensional spectrum. The type of conversion depends on whether the waves are sea or swell. This question will be repeated for each input interval (same as the wind input interval specified in question GF-33 in Part IV) unless constant input boundary conditions are specified in question BC-2.

Cautions : Improper specification of sea or swell may lead to erroneous results.

BC-13 Question : **Enter the WAVE HEIGHT >**

Options : Variable.

Preselect: BC-3, option 1.

Define : You must enter the significant (energy-based) wave height to be used as an input boundary condition.

Cautions : Units must be in meters.

BC-14 Question : **Enter PEAK WAVE PERIOD >**

Options : Variable.

Preselect: BC-3, option 1.

Define : You must enter the peak wave period associated with the wave height identified in question BC-13.

Cautions : Units must be in seconds.

BC-15 Question : **Enter MEAN PROPAGATION DIRECTION >**

Options : $0 \leq$ VALUE < 360

Preselect: BC-3, option 1.

Define : You must enter the mean propagation direction of the wave identified in question BC-13.

Cautions : Units must be in degrees using the Cartesian coordinate system shown in Figure 7-5.

BC-16 Question : **Enter WATER DEPTH >**

Options : Variable.

Preselect: BC-3, option 1.

Define : You must enter the water depth associated with the wave conditions described in questions BC-13 through BC-15. The water depth will be applied to every point along the input side of the grid (question BC-9). It is recommended that an average depth be used for the input side of the grid. Differences between the water depth entered and the actual depths along the input side of the grid will affect only the computations at the subsequent row or column.

Cautions : Units must be in meters.

PATH : o IF WAVE CHARACTERISTICS ENTERED (Option 1, question BC-3), END BOUNDARY CONDITION FILE BUILDING ROUTINE.

BC-17 Question : **Enter WAVE TYPE OPTION >**

Options : 1 - Sea wave conditions

2 - Swell wave conditions

Preselect: BC-3, option 2.

Define : SHALWV simulates both sea and swell created by winds in a two-dimensional spectrum. The spectral parameters that the boundary condition program BCGEN converts into a two-dimensional spectrum are converted based on whether the waves are locally generated wind-sea or swell. This question is repeated for each input interval (same as the wind input interval specified in question GF-33 in Part IV) unless constant input boundary conditions were specified in question BC-2.

Cautions : None.

BC-18 Question : **Enter the PEAK SPECTRAL FREQUENCY >**

Options : > 0

Preselect: BC-3, option 2.

Define : The peak frequency (f_m) of the spectrum must be specified. (See question GF-27.)

Cautions : Units must be in Hertz (Hz).

BC-19 Question : **Enter the PHILLIP'S EQUILIBRIUM CONSTANT >**

Options : $0 < \text{VALUE} \leq 0.1$

Preselect: BC-3, option 2.

Define : The Phillip's Equilibrium constant for the spectrum must be specified. (See question GF-27.)

Cautions : None.

BC-20 Question : **Enter the SPECTRAL PEAKEDNESS FACTOR >**

Options : $1 < \text{VALUE} \leq 10$

Preselect: BC-3, option 2.

Define : The "peakedness" factor for the spectrum must be specified. (See question GF-27.)

Cautions : None.

BC-21 Question : **Enter the SPECTRAL WIDTH FACTOR >**

Options : $0 < \text{VALUE} \leq 0.2$

Preselect: BC-3, option 2.

Define : The spectral peak width factor for frequencies below the peak frequency must be specified. (See question GF-27.)

Cautions : None.

BC-22 Question : **Enter the SPECTRAL WIDTH FACTOR >**

Options : $0 < \text{VALUE} \leq 0.2$

Preselect: BC-3, option 2.

Define : The spectral peak width factor for frequencies above the peak spectral frequency must be specified. (See question GF-27.)

Cautions : None.

BC-23 Question : **Enter the MEAN SPECTRAL PROPAGATION DIRECTION >**

Options : $0 \leq \text{VALUE} < 360$

Preselect: BC-3, option 2.

Define : The mean propagation direction of the spectrum must be specified. The directional distribution shape (question BC-5) will be applied about the mean propagation direction.

Cautions : Units must be in degrees using the Cartesian coordinate system shown in Figure 7-5.

BC-24 Question : **Enter the WATER DEPTH >**

Options : Variable.

Preselect: BC-3, option 2.

Define : **You must enter the water depth associated with the spectral parameters described in question BC-18 through BC-23. The water depth will be applied to every point along the input side of the grid (question BC-9). It is recommended that an average depth be used for the input side of the grid. Differences between the water depth entered and the actual depths along the input side of the grid will affect only the computations at the subsequent row or column.**

Cautions : Units must be in meters.

PATH: o IF SPECTRAL CHARACTERISTICS ENTERED (Option 2, question BC-3), END BOUNDARY CONDITION FILE BUILDING ROUTINE.

BC-25 Question : **Enter 1-D SPECTRA INPUT OPTION >**

Options : 1 - Read Headers and Spectra from a file

2 - Enter Headers and Spectra

3 - Enter Headers, Read Spectra

Preselect: BC-3, option 3.

Define : The method for entering the one-dimensional spectra must be specified. The Header includes the values for the wave type option (question BC-27), the mean spectral propagation direction (question BC-28), and the water depth for the input boundary conditions (question BC-29). If the Headers are read from a file, then questions BC-27 through BC-29 will not be asked. The data format is discussed in Part V.

Cautions : If option 2 or 3 is selected, you will be required to input the headers and/or the spectra interactively. The spectra must contain energy density values for each frequency band (see description for question GF-6 in Part IV) for each input interval (same as the wind input interval described in question GF-33 in Part IV) unless constant boundary conditions are selected in question BC-2.

PATH: o IF SPECTRAL DATA ENTERED INTERACTIVELY (Option 2, question BC-25), GO TO BC-27.

BC-26 Question : **Enter the name of the SPECTRAL DATA FILE >**

Options : Variable.

Preselect: BC-3, option 3; BC-25, options 1 or 3;

Define : The name of the file containing the one-dimensional spectral data must be entered.

Cautions : If the name entered is improper or incorrect or if an error occurs while the module reads the file, the Boundary Condition File Building session will end. No information will be saved. You will have to correct the file before rerunning the Boundary Condition File Building routine.

The file name must conform to the file naming conventions of the UNIX operating system.

PATH: o IF SPECTRAL DATA AND HEADERS ARE ENTERED BY FILE (Option 1, question BC-25), END BOUNDARY CONDITION FILE BUILDING ROUTINE.

BC-27 Question : **Enter WAVE TYPE OPTION >**

Options : 1 - Wind sea conditions

2 - Swell conditions

3 - Sea and Swell conditions

Preselect: BC-3, option 3; BC-25, options 2 or 3;

Define : The type of wave conditions represented by the one-dimensional spectra must be identified. The module uses different spectral transformation methods depending on whether it is a sea spectrum, swell spectrum, or combination of the two.

Cautions : Improper specification of the spectrum may lead to erroneous results.

BC-28 Question : **Enter MEAN SPECTRAL PROPAGATION DIRECTION >**

Options : $0 \leq$ VALUE < 360

Preselect: BC-3, option 3; BC-25, option 2 or 3;

Define : The mean direction of propagation of the spectra must be specified. The module will apply the specified directional distribution shape (question BC-5) about the mean direction.

Cautions : Units must be in degrees using the Cartesian coordinate system illustrated in Figure 7-5.

BC-29 Question : **Enter WATER DEPTH >**

Options : Variable

Preselect: BC-3, option 3; BC-25, options 2 or 3;

Define : You must enter the water depth associated with the spectra entered. The water depth will be applied to every point along the input side of the grid (question BC-9). It is recommended that an average depth be used for the input side of the grid. Differences between the water depth entered and the actual depths along the input side of the grid will affect only the computations at the subsequent row or column.

Cautions : Units must be in meters.

PATH: o IF SPECTRAL DATA IS ENTERED BY FILE (Option 3, question BC-25), END BOUNDARY CONDITION FILE BUILDING ROUTINE.

BC-30 Question : **Enter the 1-D FREQUENCY SPECTRA >**
Spectral Energy Value ##:

Options : Variable

Preselect: BC-3, option 3; BC-25, option 3;

Define : **The spectral energy density values must be entered for each frequency band in the spectrum. (See the description of spectral energy bands in question GF-6 in Part IV).**

Cautions : Units must be in m^2 / Hz.

PATH: o END BOUNDARY CONDITION FILE BUILDING ROUTINE.

BC-31 Question : **Enter 2-D SPECTRA INPUT OPTION >**

Options : 1 - Read Headers and Spectra from a file

2 - Enter Headers, Read Spectra

Preselect: BC-3, option 4;

Define : The method for entering the two-dimensional spectra must be specified. The Header includes the values for the wave type option (question BC-33), the water depth, the wind speed and wind direction.

Cautions : None.

BC-32 Question : **Enter the name of the SPECTRAL DATA FILE >**

Options : Variable

Preselect: BC-3, option 4;

Define : The Spectral Data File name must be provided. This file contains the two-dimensional wave energy spectra information in the format described in Part V.

Cautions : The file name must conform to the file naming conventions of the UNIX operating system. If no file name is provided or an error is encountered when the module reads the file, the Boundary Condition File Building routine will end. No information will be saved. You must correct the file before the Boundary Condition File Building routine can be rerun.

PATH: o IF HEADERS ARE ENTERED BY FILE (Option 1, question BC-31), END BOUNDARY CONDITION FILE BUILDING ROUTINE.

BC-33 Question : **Enter WAVE TYPE OPTION >**

Options : 1 - Wind sea conditions

2 - Swell conditions

3 - Sea and Swell conditions

Preselect: BC-3, option 4; BC-31, option 2;

Define : The type of wave conditions represented by the two-dimensional spectra must be identified. The module operates on the spectrum, depending on whether it is a locally generated wind-sea spectrum, a swell spectrum, or a combination of the two.

Cautions : None.

BC-34 Question : **Enter WATER DEPTH (m) >**

Options : Variable

Preselect: BC-3, option 4; BC-31, option 2;

Define : You must enter the water depth associated with the spectral entered. The water depth will be applied to every point along the input side of the grid (question BC-9). It is recommended that an average depth be used for the input side of the grid. Differences between the water depth entered and the actual depths along the input side of the grid will affect only the computations at the subsequent row or column.

Cautions : Units must be in meters.

BC-35 Question : **Enter WIND SPEED >**

Options : 0 < VALUE < 100

Preselect: BC-3. option 4; BC-31, option 2;

Define : The wind speed is used to separate the spectrum into wind sea and swell spectra. It is assumed that energies in spectral frequencies with phase speeds greater than the wind speed are part of the swell spectrum. Those energies in spectral frequencies with phase speeds less than the wind speed are part of the wind sea spectrum.

Cautions : The wind speed must be given in knots, and it must be the equivalent overwater, 10-m elevation, neutrally stable value. If you selected option 1 or 2 in question BC-33, then the spectrum has already been identified as sea or swell, and the wind speed entered here will be ignored.

BC-36 Question : **Enter WIND DIRECTION >**

Options : 0 ≤ VALUE < 360

Preselect: BC-3, option 4; BC-31, option 2;

Define : Wind direction associated with wind speed entered on question BC-35.

Cautions : The units must be in degrees using the Cartesian coordinate system shown in Figure 7-5.

PATH: o **END BOUNDARY CONDITION FILE BUILDING ROUTINE**

Function to Run Programs

48. If a user is ready to run the module programs for a particular application, then the task of composing and formatting all of the necessary input data into the proper files has been completed. Running the programs only entails specifying which programs should be run and, in most cases, the only program that will be specified is SHALWV. However, there may be cases where input and/or output boundary conditions are specified in which case the BCGEN program and/or the INTERP program are also run.

Running SHALWV

49. When the SHALWV program is selected, the user is asked to specify a reference name under which the SHALWV output data will be stored. The reference name must conform to the file name conventions of the UNIX operating system and must NOT have a file name extension like ".dat" or ".out." (The UNIX file naming convention is 14 significant characters.) The module uses the reference name to create up to six output files (described in Part V), each with the same name, but with different extensions. The module provides the extensions ".mtx", ".spe", ".sea", ".bnd", ".prp", and ".wrm."

50. The first output file created by SHALWV is the Wave Field File (given the ".mtx" extension), which contains wave characteristics for each grid point for each output time interval (specified in question GF-32 in Part IV) of the simulation. The second output file is the Wave Spectra File (given the ".spe" extension), which contains the one- and two-dimensional spectra for the given output locations (question GF-36 & GF-37 in Part IV) for each output time interval of the simulation. The third output file is the Wave Characteristics File (given the extension ".sea"), which contains the sea, swell, and combined sea and swell wave characteristics and the wind speed and direction for each output station and each output time interval. The remaining three SHALWV output files are optional. The first of the optional files is the Subgrid Boundary Condition File (given the extension ".bnd"), which contains the output boundary condition data that will be interpolated by INTERP for use during a subsequent SHALWV simulation. The second optional file is the Preprocessing File (given the extension ".prp"), which contains all of the time-independent variable values for use in subsequent SHALWV simulations where only the time-dependent wave conditions will be calculated. (See question GF-2 in Part IV) The third optional output file is the Warm Start File, which contains wave conditions for every grid point for use in initializing the sea-state for a subsequent SHALWV simulation. (See question GF-26 in Part IV).

Running BCGEN

51. If input boundary conditions were specified in question GF-27 in Part IV and subgrids are not specified in question GF-3 in Part IV, then the Boundary Condition File Building routine (Part IV) must be used to build the input file for BCGEN. The BCGEN program is then run prior to SHALWV to generate the input boundary conditions that SHALWV must use. Since the use of

boundary conditions in SHALWV is optional, the execution of BCGEN is also optional.

Running INTERP

52. When subgrids are specified in question GF-3 in Part IV, then INTERP must be run to interpolate data from the original SHALWV simulation for use as input boundary conditions for the subgrid simulation. Subgrids are discussed in Part II.

53. Note that to run subgrid simulations, an original grid must be run previously with output boundary locations specified at the subgrid boundaries. If an original grid has not been run or the output from the original simulation has been deleted or removed from the user's working directory, then a subgrid simulation cannot be conducted. Also, input boundary conditions as generated by BCGEN cannot be specified during a subgrid simulation because input boundary conditions must be obtained from the original SHALWV simulation. Hence, BCGEN and INTERP should not be used for the same simulation.

Function to Plot/Print SHALWV Output

54. Once SHALWV has been run successfully, the module may be used to process the output data. Options to process the data graphically and statistically are provided. The graphical option can be used to display the following plots to the user's terminal:

- a. Bottom bathymetry contours (Figure 7-14).
- b. Wave-field height and period contours.
- c. Wave-field direction vectors.
- d. One- and two-dimensional wave energy spectra for given dates and locations.
- e. Wind (Figure 7-15) and wave histories at specified locations.

The print option may be used to statistically review SHALWV results and put the following information into files:

- a. The history of peak wave height and period with associated direction at specified locations.
- b. The history of peak wave height and period with associated direction throughout the modeled region.
- c. The maximum, minimum, and mean wave statistics at specified locations.

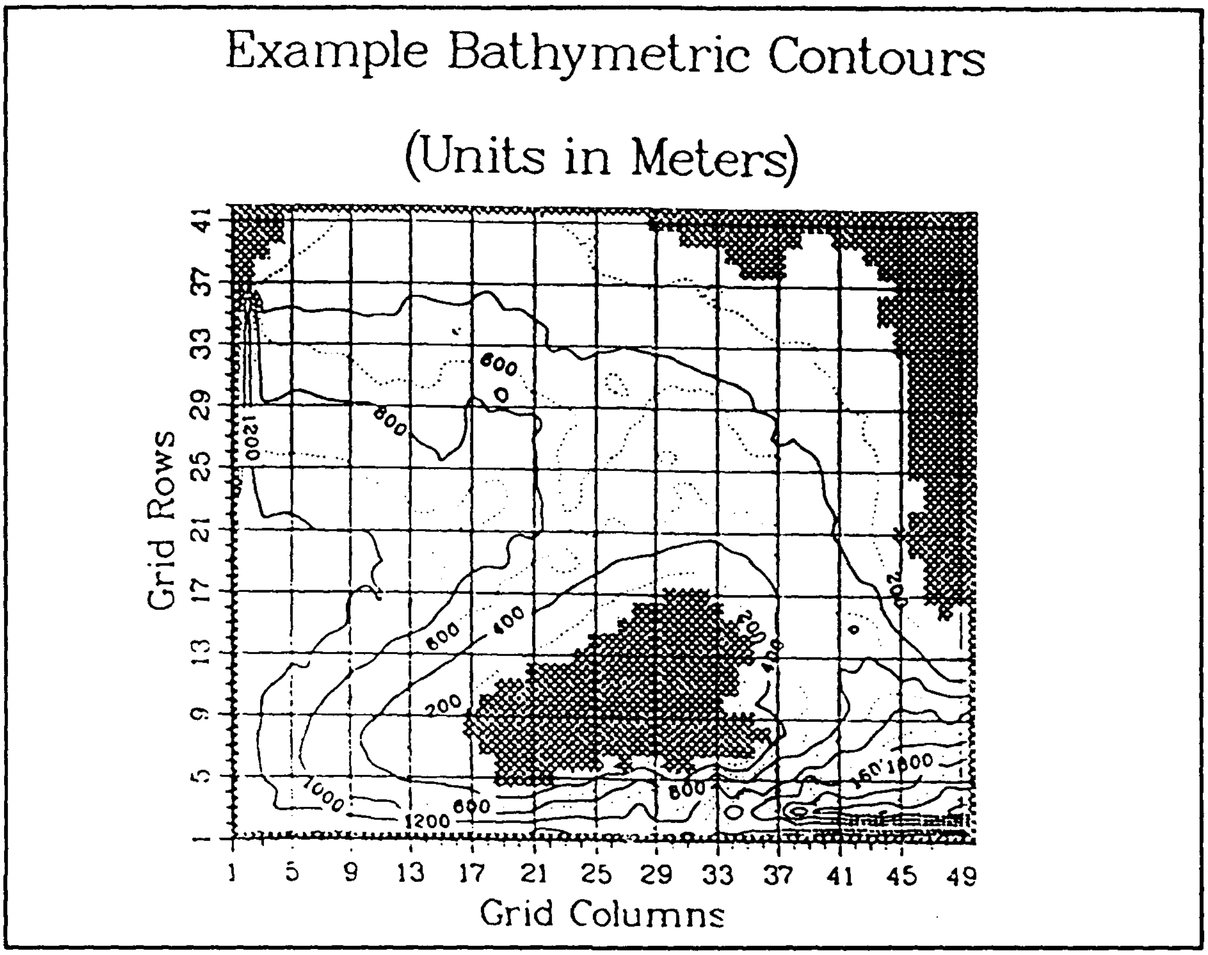


Figure 7-14. Example plot of bathymetric contours.

d. The maximum, minimum and mean wave statistics for the entire region modeled.

e. The one- and two-dimensional spectral energy data for specified locations for specified times.

The statistical computations may be displayed to the user's terminal and/or written to a file for transfer to the user's local computer for printing.

55. The data that may be evaluated by the post-processing options is based on the user-selected output data time interval and grid node location (questions GF-32 and GF-35). When necessary, the user is prompted for the desired time and location at which specified data are required. For example, if users elect to graphically display the wave direction vectors for the entire grid, they will be prompted for the date at which the information is desired. If users elect to review minimum, maximum, and mean statistics for a given location, they are prompted for the location.

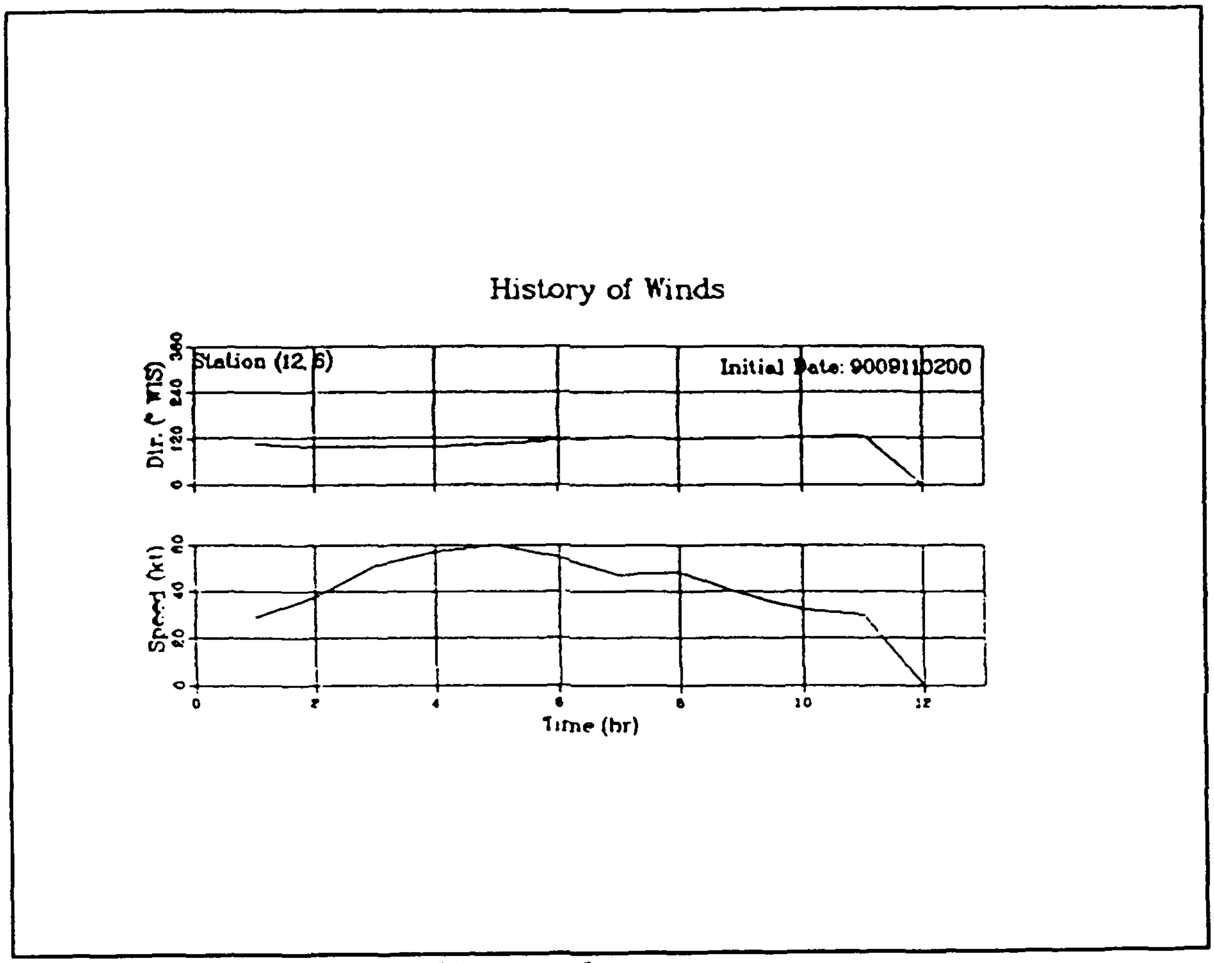


Figure 7-15. Example wind history plot.

Part V: SPECTRAL WAVE MODELING MODULE FILE DESCRIPTIONS

SHALWV Files

56. The organization of the files used in the SHALWV branch of the Spectral Wave Modeling module is shown in Figures 7-9 through 7-11. The usage of the files can be observed by determining which routines in the SHALWV branch of the module create the files and then which routines use them. This section provides a brief description of the type of data contained in each file and the format for the data within each file. A list of the files used in the SHALWV branch of the modules and their related file numbers is provided below. The reference numbers match the numbers given in Figures 7-9 through 7-11.

File Descriptions and Data Formats

57. In general, the creation, organization, and usage of almost all of the files given below are transparent to the user. The Spectral Wave Modeling module performs these tasks, prompting the user for information when necessary. Experienced users may find it useful to circumvent some of the module functions by editing and formatting data files themselves. This is generally not recommended because of the complexity of the file handling systems. The files are described below.

General Input File

58. The General Input File is one of the files built by the General File Building routine (Part IV). The General Input File contains program flow control parameters for SHALWV, spectral frequency and direction discretization parameters, computational grid parameters, land/water identifiers for each grid node, node locations for output of model results, node locations for input and output boundary condition data, and diffraction information. The format for the General Input File for preprocessing data only (option 1 in question GF-2, Part IV) follows in Table 7-1.

Table 7-1

General Input File

File Title	Name	Reference No.
General Input File	shalwvin.swv	1
Bathymetry File	depconst.swv, depvari.swv, or user specified	2
Land/Water File	user specified	3
Diffraction Data File	user specified	4
Sheltering Data File	user specified	5
Subgrid Interpolation File	intrpin.swv	6
Wind Interpolation File	user specified	7
Wind Data File (used by SHALWV)	user specified	8
Spectral Data File	user specified	9
BCGEN Input File	boundin.swv	10
Boundary Condition File (for SHALWV)	boundout.swv	11
Subgrid Boundary Condition File	user specified + ".bnd"	12
Preprocess File	user specified + ".prp"	13
Warm Start File	user specified + ".wrm"	14
Wave Field Output File	user specified + ".mtx"	15
Wave Spectra Output File	user specified + ".spe"	16
Wave Characteristic Output File	user specified + ".sea"	17
Parameter File	file1.swv	18
Main File Name File	filenmi.swv	19
Wind File Name File	filenmw.swv	20
Preprocess File Name File	filenmp.swv	21
Boundary Condition File Name File	filenmb.swv	22
Warm Start File Name File	filenmwr.swv	23
Post-Processing File Name File	filenmpst.swv	24

a. RECORD 1, Format (I5)

Field 1 - 1 (indicates preprocessing run)

b. RECORD 2, Format (6I5)

Field 1 - number of columns in grid

Field 2 - number of rows in grid

Field 3 - number of directional angle bands

Field 4 - number of frequency bands

Field 5 - 1 = frequency band values computed

2 = frequency band values specified by user

Field 6 - 1 = water depths are constant over grid

2 = water depths are variable over grid

c. RECORD 3, Format (3F8.0, F8.4)

Field 1 - distance between grid points (km)

Field 2 - a scale factor used in refraction computations expressed as a percentage of the distance between grid points. A value of 10 is recommended. A higher number increases computational time and a lower number decreases refraction accuracy.

Field 3 - computational time-step (sec)

Field 4 - factor to convert input bathymetry values to meters

d. RECORD 4

If Field 5 on RECORD 2 is 1, then Format (2F6.3)

Field 1 - Lowest frequency band value

Field 2 - Frequency band value interval

If Field 5 on RECORD 2 is 2, then Format (10F6.3)

Field 1 through 10 - Frequency band values. Up to two RECORDS may be used for input of frequency values.

e. RECORD 5, Format (100I1)

Field 1 through 100 - Array designating grid points as water (1), land (0), or grid boundary (0). This matrix must have the same dimensions as and be consistent with the bathymetry data.

59. The format for the General Input File for computing the wave field only (option 2 in question GF-2, Part IV) follows.

a. RECORD 1, Format (I5)

Field 1 - 2 (indicates wave calculation only)

b. RECORD 2, Format (I5)

Field 1 - 1 = cold start, no save

2 = warm start, no save

3 = cold start, save

4 = warm start, no save

Field 2 - 1 = No input or output boundary conditions

2 = Output boundary conditions only

3 = Input boundary conditions only

4 = Input & output boundary conditions

Field 3 - 1 = Constant winds over space and time

2 = Time-varying winds only

3 = Time- and space-varying winds

Field 4 - 1 = No bottom effects

2 = Bottom effects

c. RECORD 3, Format (2F10.5)

If Field 4 on RECORD 2 is 2, then this card is used.

Field 1 - Bottom friction coefficient

Field 2 - Bottom percolation factor

d. RECORD 4, Format (I5)

Field 1 - Number of time steps between output results

Field 2 - Number of hours between input winds

Field 3 - Maximum number of wind input

Field 4 - Number of special output locations (≤10)

e. RECORD 5, Format (2I5)

If Field 4 on RECORD 4 is > 0, then

Field 1 - Column location of special output location

Field 2 - Row location of special output location

The number of these cards must be equal to the value of Field 4 on RECORD 4.

NOTE: The remaining cards pertain to the input or output of boundary information. To make use of the data specified by these cards the BCGEN or INTERP programs must be run prior to SHALWV.

f. RECORD 6, Format (I5)

If Field 2 on RECORD 2 is 2 or 4, then this card is used.

Field 1 - Number of computational time-steps between output of boundary condition information for subgrids.

g. RECORD 7, Format (I5)

If Field 2 on RECORD 2 is 2 or 4, then this card is used.

Field 1 - Number of subgrid boundary condition output locations

h. RECORD 8, Format (2I5)

If Field 2 on RECORD 2 is 2 or 4, then a total number of cards equal to the value in Field 1 of RECORD 7 must be provided.

Field 1 - Column location of subgrid output location

Field 2 - Row location of subgrid output location

i. RECORD 9, Format (I5)

If Field 2 on RECORD 2 is 3 or 4, then this card is read.

Field 1 - Number of input boundary locations

Field 2 - The column location of the first corner location for boundary condition input

Field 3 - The row location of the first corner location for boundary condition input.

Fields 2 and 3 are repeated for the each additional corner entered for input of boundary conditions.

j. RECORD 10, Format (2I5)

If Field 2 on Card 2 is 3 or 4, then a total number of cards equal to the value entered on RECORD 7 must be provided.

Field 1 - Column location of boundary input location

Field 2 - Row location of boundary input location

60. The format for the General Input File for preprocessing and computing the wave field together (option 3 in question GF-2, Part IV) is a combination of the format for "preprocessing only" and "computing-waves only."

a. RECORD 1, Format (I5).

Field 1 - 3 (indicates a preprocess and compute waves run)

b. RECORDS 2 through 5.

These cards are identical to RECORDS 2 through 5 of a preprocessing only file.

c. RECORDS 6 through 13.

These cards are identical to RECORDS 2 through 10 of a "compute waves only" file.

Bathymetry File

61. The bathymetry file can be built during operation of the General File Building routine (Part IV). However, because the number of bathymetry data is usually large, it is recommended that users build this file using the most convenient editor available to them. The bathymetry file is a matrix of numbers indicating the depth at each point on the computational grid. (See questions GF-18 through GF-21 in Part IV for additional information.) Depth

values may be entered in any units desired, but they must all have the SAME units.

If Field 6 on RECORD 2 of the General Input File is 1, then Format (F6.0).

Field 1 - Uniform (constant) water depth value. If Field 6 on RECORD 2 of the General Input File is 2, then Format (21F6.0).

Field 1-21 - Matrix of depth values for each point on the computational grid. Note that this matrix must match the Land/Water matrix. Values equal to (0.0) are assumed to be land.

Note: Only 21 values are allowed per row. If the computational grid has more than 21 values on a row, then 21 values are entered on the first card and the remaining numbers are placed on additional cards until the entire row of values has been entered. The next row of the computational grid begins on a new card.

62. An option is available in the General File Building routine which allows you to build the Land/Water file (see next file description) based on the values in the Bathymetry File. The General File Building routine reads the Bathymetry File and assigns land values to grid points with depths equal to (0.0) and to the grid borders. All other points are assigned water values.

Land/Water File

63. The Land/Water File can be built by the General File Building routine or read from a file (Part IV). An option is available within the General File Building which allows the user to create the Land/Water file based on the bathymetry data values. (See Bathymetry File Description.) The Land/Water File is a matrix of ones (1) and zeroes (0) al Fh indicates whether a grid point is a land point (or grid border), or water point, respectively. The dimensions of the Land/Water File data must be the same as the data in the Bathymetry File. The Land/Water File is placed within the General Input File by the General File Building routine. The above description of the General Input File shows how the Land/Water data is positioned.

RECORD 1, Format (100I1).

Field 1 through 100 - Enter a one (1) or a zero (0) for each grid point along a row of the computational grid. Subsequent rows of the grid must be provided on additional RECORDS.

Diffraction Data File

64. The Diffraction Data File contains data required by SHALWV to perform diffraction computations. The data include the locatioon on the grid of the diffracting point and the position of the diffracting structure. These

data are described in Part II and in question GF-55 in Part IV. These data may also be entered interactively during the General File Building Routine (Part IV). The format for the data within the file is given below.

a. RECORD 1, Free Format.

Field 1 - Column locatioon of diffracting point.

Field 2 - Row location of diffracting point.

Field 3 - Position number of diffracting structure.

b. RECORD 2.

Repeat RECORD 1 for additional diffraction locations.

Sheltering Data File

65. The Sheltering Data File contains data required by SHALWV to reduce wave energy to user-specified levels at user-specified locations. The data include the sheltered point's location on the grid, as well as coefficients which specify the amount of energy reduction per angle band within the energy spectrum. These data described in Part II and questioon GF-61 in Part IV. The data may also be entered interactively via the module as described in Part IV. The format for the data within the file is given below.

a. RECORD 1, Free Format.

Field 1 - Column location of sheltered point.

Field 2 - Row location of sheltered point.

Field 3-18 - Sheltering coefficient for each of the 16 angle bands in the spectrum incremented from 0° by 22.5° steps.

Note:

(1) Sixteen direction bands is default value when sheltering is used.

(2) Coefficient indicates percent sheltered, e.g., a coeffi cient of one indicates 100 percent sheltered.

b. RECORD 2.

Repeat RECORD 1 for any additional sheltered locations.

Subgrid Interpolation File

66. The Subgrid Interpolation File is an optional file created by the General File Building routine and is needed only when a subgrid of an original computational grid is being used. The Subgrid Interpolation File contains parameter values that control operation of the subgrid input boundary condition interpolation program, INTERP. The INTERP interpolates the output boundary condition information from an original SHALWV simulation to the input boundary locations of a subgrid. (See Part II for a description of subgrids.)

It is recommended that users not modify this file except through the General File Building routine. The General File Building routine will keep track of the association between input and output boundary locations and maintains complete consistency between general program control parameters for the original SHALWV simulation and the subgrid simulation.

<u>a</u>. RECORD 1, Format (8I5).

Field 1 - Number of Columns in Subgrid.

Field 2 - Number of Rows in Subgrid.

Field 3 - Number of output boundary condition locations on original grid.

Field 4 - Number of input boundary condition locations on subgrid.

Field 5 - Ratio between length of original and subgrid cell lengths.

Field 6 - Number of frequency bands in spectrum.

Field 7 - Number of direction bands in spectrum.

Field 8 - 1 = frequency bands were computed.

2 = frequency bands were entered by user.

<u>b</u>. RECORD 2.

If Field 5 on RECORD 2 of the General Input File (see above) is one (1), then FORMAT (2F7.4).

Field 1 - Initial frequency band value.

Field 2 - Interval value between frequency bands.

If Field 5 on RECORD 2 of the General Input File (see above) is two (2), then FORMAT (10F7.4).

Field 1 through 10 - Frequency band values for the number of frequency bands specified on Field 4 of RECORD 2. If more then 10 values are required an additional card may be used.

<u>c</u>. RECORD 3, Format (F8.4).

Field 1 - Depth conversion factor.

<u>d</u>. RECORD 4, Format (3I5).

This card is repeated for each input boundary location on the subgrid.

Field 1 - Input boundary condition column location.

Field 2 - Input boundary condition row location.

Field 3 - 0 = point does not correspond with a point on the original grid.

1 = point corresponds with a point on the original grid.

Wind Input File (used by SHALWV)

67. The Wind Input File contains the wind input data formatted for use by SHALWV. This is in contrast to the Wind Interpolation File, which contains meteorological station information that is used to generate a Wind Input File by the Wind File Building routine (Part IV). Because of the method used to keep track of files within the module, it is recommended that the Wind Input File be passed through the Wind File Building routine (Part IV) so that the module can "tag" the file for use. The Wind Input File may be created outside the module on the user's preferred editor, but the name of the file should be given to the module through the Wind File Building routine.

68. The Wind Input File is required for any SHALWV simulation except a "preprocessing data only" simulation. A wind field can be input as either a single card specifying a uniform and constant wind speed and wind direction over the entire grid, or in the form of matrices that give the wind speed and direction at each grid point. The wind file can contain any number of wind fields, but it must contain at least two (for nonconstant wind fields).

Uniform and Constant Wind Field

69. The Uniform and Constant Wind Field is specified in Field 3 of RECORD 6 of the General Input File for both preprocessing and computing waves.

RECORD 1, Format (2F6.1).

Field 1 - Uniform wind speed in knots. Assumed overwater, neutrally stable atmospheric conditions at the 10-m elevation.

Field 2 - Uniform wind direction in degrees over entire grid expressed in Cartesian system.

Time-Varying Wind Field File

70. Time-Varying Wind Field File is specified in Field 3 of RECORD 6 of the General Input File for both preprocessing and computing waves.

RECORD 1, Format (I10,2F6.1) (This card is repeated for the number of wind inputs desired and specified in the General Input File.)

Field 1 - Date in the form 'yymmddhh'

Field 2 - Same as Field 1 for constant winds

Field 3 - Same as Field 2 for constant winds

Time- and Space-Varying Wind Field File

71. The Time- and Space Varying Wind Field File is specified in Field 3 of RECORD 6 of the General Input File for both preprocessing and computing waves. The wind field data are entered differently than the data for the bathymetry. For example, if the computational grid has more than 21 columns,

say 30, then the first 21 columns are read for all rows of the grid for wind speed, and then the first 21 columns are read for all rows for wind direction. Then, the remaining 9 columns for all rows are read for wind speed, and then the remaining 9 columns for all rows are read for wind direction.

a. RECORD 1, Format (I10).

   Field 1 - Date in the form 'yymmddhh'.

b. RECORD 2, Format (21F6.1) (This card is repeated as necessary to input all of the wind values.)

   Field 1 through 21 - Wind speeds as defined in Field 1 of the constant wind-field file description.

   A card for every row is entered containing the first 21 columns of wind data.

c. RECORD 3, Format (21F6.1).

   Field 1 through 21 - Wind directions as defined in Field 2 of the constant wind-field file description.

RECORDS 2 and 3 are repeated until all columns of the grid have been entered. RECORDS 1, 2, and 3 are repeated until all the wind data for the simulation have been entered.

Wind Interpolation File (provided by user to Wind File Building routine)

72. The Wind File Building routine has the provision to interpolate wind data from meteorological stations located over the water (e.g. buoy data) to every point on the computational grid.

a. RECORD 1, Free Format.

   Field 1 - number of stations included in the interpolation (max. 100).

b. RECORD 2, Free Format.

   Enter the column location for every meteorological station.

c. RECORD 3, Free Format.

   Enter the row location for every meteorological station in the same order used on RECORD 2.

d. RECORD 4, Free Format.

   Enter the wind speed and direction for each station for the first wind input interval. On additional cards, add the wind speed and direction for each station for the remaining wind input intervals.

BCGEN Input File

73. The BCGEN Input File is generated by the Boundary Condition File Building routine to be used as input to the BCGEN program. The BCGEN Input File contains the program control parameters and necessary information for

generating boundary conditions at user-specified locations on the computational grid. It is recommended that this file be created and modified only through the Boundary Condition File Building routine, so that consistency can be maintained in file organization and program control parameters.

a. RECORD 1, Format (2I5).

Field 1 - 1 = Boundary Conditions are constant.
2 = Boundary Conditions are time-varying.

Field 2 - 1 = Wave characteristics are specified.
2 = Wave spectral parameters are specified.
3 = One-Dimensional spectra are specified.
4 = Two-Dimensional spectra are specified.

b. RECORD 2, Format (8I5).

Field 1 - Number of spectral frequency bands.

Field 2 - Number of spectral direction bands.

Field 3 - 0 = frequency band values are computed.
1 = frequency band values are entered.

Field 4 - Spectral shape criteria where:
1 = Kittigoradskii
2 = Pierson-Moskowitz
3 = JONSWAP
4 = TMA

Field 5 - Spectral spreading function where:
1 = $\cos^{nn}$
2 = $\cos^{2p}$ (Gamma Function)

Field 6 - Specifies the side of the computational grid through which the spectrum is principally propagating. (See question BC-9 for definition.)

Field 7 - Specifies whether more than one side of the computational grid are given input boundary conditions. (See question BC-10 for definition.) Note that:
0 = no other sides
1 = left side only
-1 = right side only
2 = both left and right sides

Field 8 - Specifies method for determining 'p' in spectral spreading function specified in Field 5 where:
0 = 'p' computed
1 = 'p' entered

c. RECORD 3, Format (I5) If Field 5 on RECORD 2 is 1, then this card is used.

Field 1 - nn, the spectral spreading exponent.

d. RECORD 4, Format (F5.1) If Field 5 on RECORD 2 is 2 and Field 8 on RECORD 2 is 1, then this card is used.

Field 1 - p, the spectral spreading exponent.

e. RECORD 5, Format (10F7.4) If Field 3 on RECORD 2 is 1, then this card is used.

Field 1 through 10 - frequency band values (Hz). An Additional card may be used.

f. RECORD 6, Format (2F7.4) If Field 3 on RECORD 2 is 0, then this card is used.

Field 1 - Initial frequency band value.

Field 2 - Frequency band value interval.

g. RECORD 7, Format (I5).

Field 1 - Maximum number of input intervals.

h. RECORD 8, Format (I5).

Field 2 -Number of input boundary condition locations.

i. RECORD 9, Format (3I5, F8.2).

Field 1 - Grid input side identifier where:

0 = Main input side

1 = Input side to the left of the main side

-1 = Input side to the right of the main side

Field 2 - Input boundary condition column location.

Field 4 - Input boundary condition row location.

Field 5 - Depth at input boundary condition location.

This card is repeated for each input boundary condition location. If Field 2 of RECORD 1 is 1, then this card is used. A card is required for each input time interval.

j. RECORD 10, Format (I5, 4F6.1, I10).

Field 1 - Wave type option

Field 2 - Wave height (m)

Field 3 - Wave period (sec)

Field 4 - Wave propagation direction (° Cartesian)

Field 5 - Water depth (m)

Field 6 - Date/time for input (yymmddhh)

If Field 2 of RECORD 1 is 2, then this RECORD is used. A card is required for each input time interval.

k. RECORD 11, Format (I5, 2F6.4, 2F6.1, F6.1, F7.2, I10).

Field 1 - Wave type option.

Field 2 - Peak spectral frequency (Hz), f_m.

Field 3 - Phillip's Equilibrium Constant, α.

Field 4 - Spectral peakedness factor, γ.

Field 5 - Frequency shape factor, σ_a.

Field 6 - Frequency shape factor, σ_b.

Field 7 - Mean propagation direction (° Cartesian).

Field 8 - Water depth (m).

Field 9 - Date/time for input (yymmddhh).

If Field 2 of RECORD 1 is 3, then RECORD 12 and 13 are used. A set of cards is required for each input time interval.

k. RECORD 12, Format (I5, 2F6.1, I10).

Field 1 - Wave type option.

Field 2 - Mean propagation direction (° Cartesian).

Field 3 - Water depth (m).

Field 4 - Date/time for input (yymmddhh).

l. RECORD 13, Format (10F6.2).

Field 1 through 10 - Spectral energy values for each frequency band in m^2/Hz. Values must be provided from lowest to highest frequency band.

An additional card may be used for more frequency bands.

If Field 2 of RECORD 1 is 4, then RECORD 14 and 15 are used. A set of cards is required for each input time interval.

m. RECORD 14, Format (I5, 3F6.1, I10).

Field 1 - Wave type option.

Field 2 - Water depth (m).

Field 3 - Wind speed (knots).

Field 4 - Wind direction (° Cartesian).

Field 5 - Date/time for input (yymmddhh).

n. RECORD 15, Format (16F8.5).

Field 1 through 10 - Spectral energy values for each direction band for a given frequency band (units are $m^2/(Hz \cdot rad)$). Values must be provided starting with the 0° band and the lowest frequency band.

Additional cards may be used for more frequency bands.

Spectral Data File

74. The Spectral Data File contains wave energy spectra that the Boundary Condition File Building routine (Part IV) uses to generate boundary

conditions for SHALWV. The Spectral Data File may contain either one- or two-dimensional spectral information for each input time-step (same as the wind input time-step specified in question GF-33 in Part IV). If time-invariant boundary conditions are specified during the Boundary Condition File Building routine, then only one spectrum is required for each input station. Descriptions for the question numbers provided with the file data format below can be found in Part IV.

One-Dimensional Input Boundary Condition Spectra

a. RECORD 1, Free Format.

This card is only used if Headers are specified as being read from a file during the Boundary Condition File Building routine.

Field 1 - Wave type option (question BC-27).

Field 2 - Mean propagation direction (question BC-28).

Field 3 - Water depth (question BC-29).

b. RECORD 2, Free Format.

The fields on this card are filled (up to 132 characters/card). Several cards may be used to enter all of the spectral values. The frequency values should be in units of m^2/Hz. The values should be provided from the lowest to the highest frequency band.

RECORDS 1 and 2 are repeated for each data input time.

Two-Dimensional Input Boundary Condition Spectra

a. RECORD 1, Free Format.

This card is only used if Headers are specified as being read from a file during the Boundary Condition File Building routine.

Field 1 - Wave type option (question BC-32).

Field 2 - Water depth (question BC-33).

Field 3 - Wind speed (question BC-34).

Field 4 - Wind direction (question BC-35).

b. RECORD 2, Free Format.

The fields on this card are filled (up to 132 characters/card) until all of the spectral values for a given frequency are entered. Several cards may be used. The spectral energy is entered for each direction band for a given frequency beginning with the band at 0° in a Cartesian coordinate system. (See Figure 7-5.) After the values for each direction in a frequency band have been entered, a new frequency band is selected and

a new card must be used. Several cards may be used. The frequency values should be in units of $m^2/(Hz \cdot rad)$. The data should be provided from the lowest to the highest frequency band.

RECORDS 1 and 2 are repeated for each data input time interval.

Boundary Condition File (for SHALWV)

75. The Boundary Condition File (for SHALWV) is output from the BCGEN program, which is used to generate input boundary conditions for a given SHALWV simulation. The data for this file are written in binary, and therefore the format is not described.

Subgrid Boundary Condition File

76. The Subgrid Boundary Condition File is created by SHALWV for use by INTERP. SHALWV fills the file with boundary condition information for a subsequent subgrid simulation. INTERP interpolates the data to fit the subgrid cell size. The data are written to the file in binary form. Therefore, format and data within the file are not described.

Preprocess File

77. The Preprocess File is generated by SHALWV. It contains all of the time-independent parameters for a given application. It is accessed by SHALWV in future simulations where the wave fields are calculated (i.e., where only the time-dependent values are calculated). The file is written in binary; therefore, the file data and format are not described.

Warm Start File

78. The Warm Start File is generated by SHALWV at the end of a simulation. The Warm Start File is used to initialize the two-dimensional spectrum at every computational grid point for a subsequent SHALWV simulation, which therefore can continue the previous simulation. This process removes discontinuities between individual segments of a long simulation. The file data are written in binary; therefore, the file data and format are not described.

Wave Field Output File

79. The Wave Field Output File contains the energy-based significant wave height, the peak spectral period, and the mean spectral direction of propagation for each point on the computational grid for each output time-step as specified in question GF-32 in Part IV. The data are oriented in the file for a given output interval with the matrix of wave heights provided first, followed by the wave period, and then the direction.

Wave Spectra Output File

80. The Spectra Output File contains the two-dimensional energy spectra for each output station specified in questions GF-35 and GF-36 for each output time interval specified in question GF-32 in Part IV. The first line contains (from left to right) the date, the column and row for the output location, the assigned station number, the wind-sea spectral parameters including the Phillips' Equilibrium constant, peak spectral frequency, spectral peakedness factor, frequency band number, wave direction band number (in 5° intervals), mean direction of the wind sea (in radians), wave number, and amount of energy in the parametric region of the spectrum.

81. The matrix that follows the first line contains both the one- and two-dimensional spectrum, the specified location, and date. The first column contains the one-dimensional (in frequency) wave energy spectrum (cm^2). The top of the column corresponds to the lowest frequency. The frequency values associated with the energy values in the first column were specified through questions GF-6 and GF-14 (or GF-6, GF-15, and GF-16). The other columns contain the two-dimensional spectrum in cm^2. Each row corresponds to the same frequency as the frequency in the adjacent one-dimensional spectrum. The two-dimensional spectrum is always output using only 16 direction bands regardless of what was specified in question GF-7 in Part IV. The first column corresponds to the direction band CENTERED ON 0 deg. Each direction band is 22.5 deg wide.

Wave Characteristic Output File

82. The Wave Characteristics Output File contains the energy-based wave height, peak spectral period, and mean spectral propagation direction for the total energy spectrum, the wind-sea spectrum, and the swell spectrum, as well as the wind speed and direction for the output locations specified in questions GF-35 and GF-36 for each output interval specified by question GF-32 in Part IV. The numbers in each row have the following definitions: (from left to right)

1. The date (yymmddhhmm).
2. The location identifying number (station number).
3. The column and row of the output location.
4. The wave height of the total spectrum (m).
5. The peak period of the total spectrum (sec).
6. The mean propagation direction of the total spectrum (° Cartesian).

7. The wave height of the sea spectrum (m).

8. The peak period of the sea spectrum (sec).

9. The mean propagation direction of the sea spectrum (° Cartesian).

10. The wave height of the swell spectrum (m).

11. The peak period of the swell spectrum (sec).

12. The mean propagation direction of the swell spectrum (° Cartesian).

13. The wind speed (knots).

14. The wind direction (° Cartesian).

<u>Parameter File</u>

83. The Parameter File is created by the General File Building routine. The values in the parameter file are used to dimension variables in SHALWV. The SHALWV program uses the Fortran command "INCLUDE" to include the file within the program during compilation. The file contains a FORTRAN "PARAMETER" statement. The variables in the "PARAMETER" statement are defined as:

IDMN - Number of columns in the computational grid.

JDMN - Number of rows in the computational grid.

IF - Number of spectral frequency bands.

IA - Number of spectral direction bands.

KSST - Number of water points within the grid.

(The number of water points is calculated during the General File Building Routine based on the number of ones (1) in the LAND/WATER matrix.)

MKST - Number of shallow-water points within the grid.

(The number of shallow-water points is calculated during the General File Building Routine based on the number of points in the grid where the depth-to-wavelength ratio is less than one-half (1/2).

NBPS - Largest number of input or output boundary condition points.

NDIF - Number of diffraction points.

<u>Main File Name File</u>

84. The Main File Name File contains the names of the General Input File, the Bathymetry File, and the Sheltering File. It also provides parameter values indicating the SHALWV process option, the input/output boundary condition option, the warm-start / cold-start option, as well as estimates of how much time and memory SHALWV will demand from the computer for the specified application. The format for the Main File Name File is provided.

a. **RECORD 1, Free Format.**

Field 1 - Process Option (Question GF-2, Part IV).

b. RECORD 2, Free Format.

Field 1 - General Input File Name.

c. RECORD 3, Free Format.

Field 1 - Bathymetry Data File Name.

d. RECORD 4, Free Format.

Field 1 - Sheltering Data File Name.

e. RECORD 5, Free Format.

Field 1 - Boundary condition option number. (See question GF-27 in Part IV)

Field 2 - Start-up Option number. (See question GF26 in Part IV)

f. RECORD 6, Free Format.

Field 1 - Estimate of CPU time for simulation in seconds.

Field 2 - Estimate of core storage for simulation.

Wind File Name File

85. The Wind File Name File is created by the Wind File Building routine and contains the name of the wind-field file to be used by SHALWV. The format for the Wind File Name File is provided below.

RECORD 1, Free Format.

Field 1 - Wind Input File Name.

Preprocess File Name File

86. The Preprocess File Name File is created when SHALWV is run. The name of the Preprocess File generated by SHALWV is placed in the Preprocess File Name File. The format for the Preprocess File Name File is provided below.

RECORD 1, Free Format.

Field 1 - Preprocess File Name.

Boundary Condition File Name File

87. The Boundary Condition File Name File contains the name of the Subgrid Boundary Condition File generated by SHALWV. The format for the Boundary Condition File Name File is provided below.

RECORD 1, Free Format.

Field 1 - Boundary Condition File Name.

Warm Start File Name File

88. The Warm Start File Name File contains the name of the Warm Start File generated by SHALWV. The format for the Warm Start File Name File is provided below.

RECORD 1, Free Format.

Field 1 - Warm Start File Name.

Post-Processing File Name File

89. The Post-Processing File Name File contains the names of the data output files generated by SHALWV. The files included the Wave Field Output File, the Wave Characteristic Output File, and the Wave Spectra File. The format for the Post-Processing File Name File is provided below.

RECORD 1, Free format.

Field 1 - Name of the ".sea" file.

Field 2 - Name of the ".spe" file.

Field 3 - Name of the ".mtx" file.

(See Part IV for description.)

Example Data Sets

SHALWV Module example data set

90. A description of an example test case for SHALWV is included here. The example is designed to provide a data set with which SHALWV can be run, allowing the users to familiarize themselves with the Spectral Wave Modeling Module. The example is an idealized situation where a body of water of constant depth is subjected to a constant wind with no other forcing condition such as incoming waves. In essence, the example provides an indication of wind-wave growth capabilities of the SHALWV model. The computational grid is illustrated in Figure 7-16.

91. The instructions and data values that follow should be used to conduct the example test simulation.

Instructions and data for example case

92. Building the General Input File. The following items are provided in the order in which they will be requested.

a. Enter the SHALWV module through the CMS menu.

b. Select "Building Files" from the main menu.

c. Select "General File Building" from the "Building Files" menu.

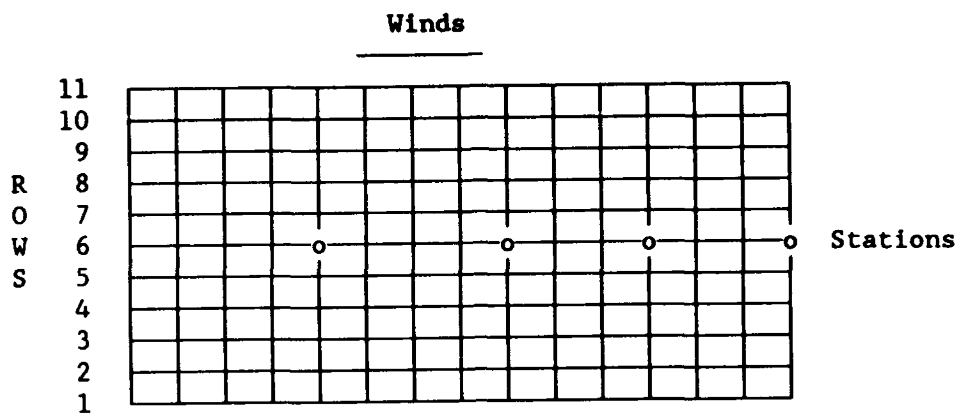


Figure 7-16. Example case computational grid

(The following data will be requested by the module. Use the provided data only to ensure a successful simulation.)

(1) Select either 80- or 132-character screen width .

(2) Select "preprocess and calculate wave field" option.

(3) Select "Not a subgrid run" option.

(4) Number of COLUMNS in grid is 15.

(5) Number of ROWS in grid is 11.

(6) Number of FREQUENCY BANDS is 20.

(7) Number of direction ANGLE BANDS is 16.

(8) Select "Frequency Band Values computed" option.

(9) Select "Constant Water Depth" option.

(10) Depth Conversion Factor is 1.0.

(11) Distance Between Grid Points is 50 km.

(12) Refraction Scale Factor is 10.

(13) Computational Time-Step is 900 sec.

(14) First Frequency Band Value is 0.03 Hz.

(15) Frequency Band Value Interval is 0.02 Hz.

(16) Constant Water Depth is 1,000 m.

(17) Select "Generate Test Matrix" option for Land/Water Matrix.

(18) Select "Cold Start/No Save" option.

(19) Select "No Input Boundary Conditions" option.

(20) Select "Constant Winds" option.

(21) Select "No Bottom Effects" option.

(22) Number of Time Steps Between Output is 4.

(23) Number of Hours Between Wind Inputs is 1.

(24) Number of Wind Inputs is 48.

(25) Number of Special Output Locations is 4.

(26) Special Output Locations are
5, 6 9, 6 12, 6 15, 6

(27) Select "No Diffraction" option.

(28) Select "No Sheltering" option.

d. At this point, all of the General Input File data have been entered. You may, at your discretion, press RETURN as needed to work through the summary that follows at the data input session. You will then be returned to the "Building Files" menu.

93. Building the Wind Field File. Select "Build Wind Field File" from the "Building Files" menu. (The following data will be requested by the module. Use the provided data only to ensure a successful simulation.)

a. Answer "yes" when asked whether General Input File Building has been run. (It was done in Step 1.)

b. The "Wind Speed Convention" option is 1 (for meters/second).

c. The "Wind Direction Convention" option is 1 (for Cartesian, toward which the winds blow).

d. Wind Speed Value is 20 m/sec (constant).

e. Wind Direction Value is 0 deg (constant).

f. Output file name is WINDS.

94. The module will then return you to the "Building Files" menu. Press "0" to return to the main module menu.

Running the SHALWV program

a. Select "Run Programs" from the "Main Menu".

b. Select "Run SHALWV" from the "Run Programs" menu and provide an output file name called EXAMPLE when prompted to do so.

c. At this point, the SHALWV program is submitted to the CRAY Y-MP batch queues for execution. This particular application requires only about 1 min of the CRAY Y-MP's CPU time to compile and link the SHALWV program and to execute the simulation.

d. Press RETURN until the "Run Programs" menu appears. Press "0" to return to the "Main Menu".

Graphically view the results

a. At the "Main Menu", select "Plot/Print Results" to graphically view the results of this example case.

b. At the "Plot/Print Menu" select "Graphics".

c. At the "Plot Options" menu, select the type of plot to view. (The bathymetric contour plot is not recommended since a constant depth was used for the simulation.) The following provides information for creating any of the available plots.

Wave field plots

a. Select "Wave Field Plot" from the "Graphics" menu.

b. Answer "no" to the question about Customizing your plot.

c. Select either "Wave Height Contours," "Wave Period Contours," or "Wave Direction Vectors."

d. Select the dates for which plots should be created. You must select the starting date number, the ending date number, and the interval between dates. If you want only one plot, enter the appropriate date number as both the starting and ending date numbers.

e. After a brief pause, a message will be issued indicating that the metafile containing the plots has been generated. Press RETURN, and select the appropriate device-type for viewing the plots on your terminal. At the "Enter Plot Directives" prompt, enter a RETURN. The first plot will be drawn on your screen. When you wish to proceed to the next plot, press a RETURN. Figures 7-17 through 7-19 contain plots of the wave height and period contours and wave direction vectors for the 36th hour of the 48-hr simulation.

NOTES:

(1) If the dates selected for plotting are early in the simulation, there may be little information presented in the plot because the wave conditions have not had sufficient time to develop. Plots for dates late in the simulation will have more information, since waves are approaching fully developed conditions.

(2) While evaluating the plots, note that the wind is blowing from left to right across the grid (0 deg) and therefore wave conditions increase in the same direction.

Spectral Plots

a. Select "Spectral Plots" option from the "Graphics" menu.

b. Answer "no" to the question about Customizing your plot.

c. Select either "One-Dimensional Spectra" or "Two-Dimensional Spectra."

d. Select the station at which the spectral information is desired. Figure 16 shows the locations of the stations on the computational grid.

e. Select the dates for which plots should be created. You must select the starting date number, the ending date number, and the interval between dates. If you want only one plot, enter the appropriate date number as both the starting and ending date numbers.

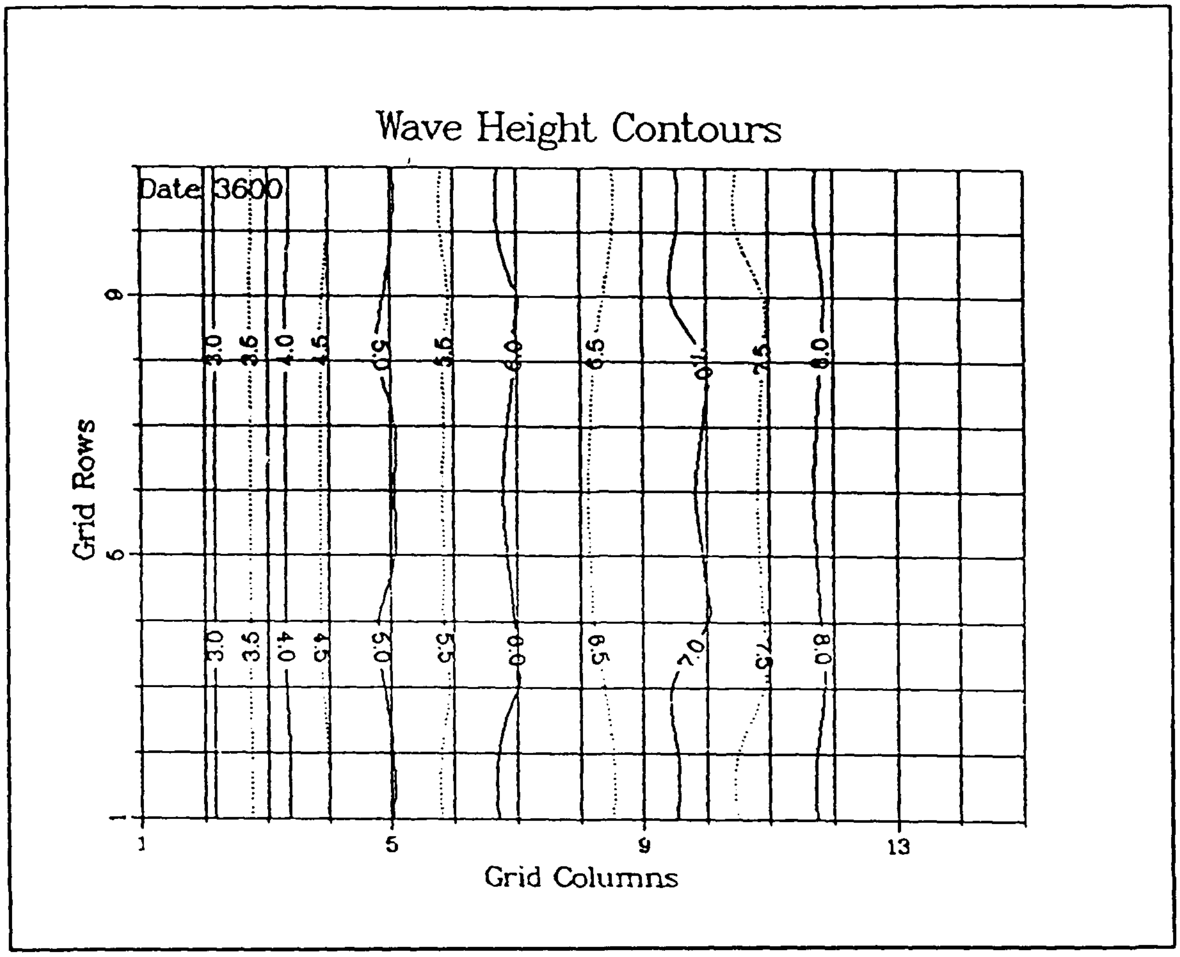


Figure 7-17. Wave height contours for the 36th hr of the example simulation

f. After a brief pause, a message will be issued indicating that the metafile containing the plots has been generated. Press RETURN, and select the appropriate device-type for viewing the plots on your terminal. At the "Enter Plot Directives" prompt, enter a RETURN. If one-dimensional spectra are being plotted, all of the spectra (one for each date selected) will be plotted on the same graph. If two-dimensional spectra are being plotted, each spectrum is presented in contour form with only one spectrum per plot. When you wish to proceed to the next plot, press a RETURN. Figures 20 and 21 contain plots of the one- and two-dimensional spectra computed at station 3 (location 12, 6) for the 36th hour of the 48-hr simulation.

Wave/Wind History Plots

a. Select "Wave/Wind History Plot" from the "Graphics" menu.

b. Answer "no" to the question about Customizing your plot.

c. Select "Wave History Plots" or "Wind History Plots."

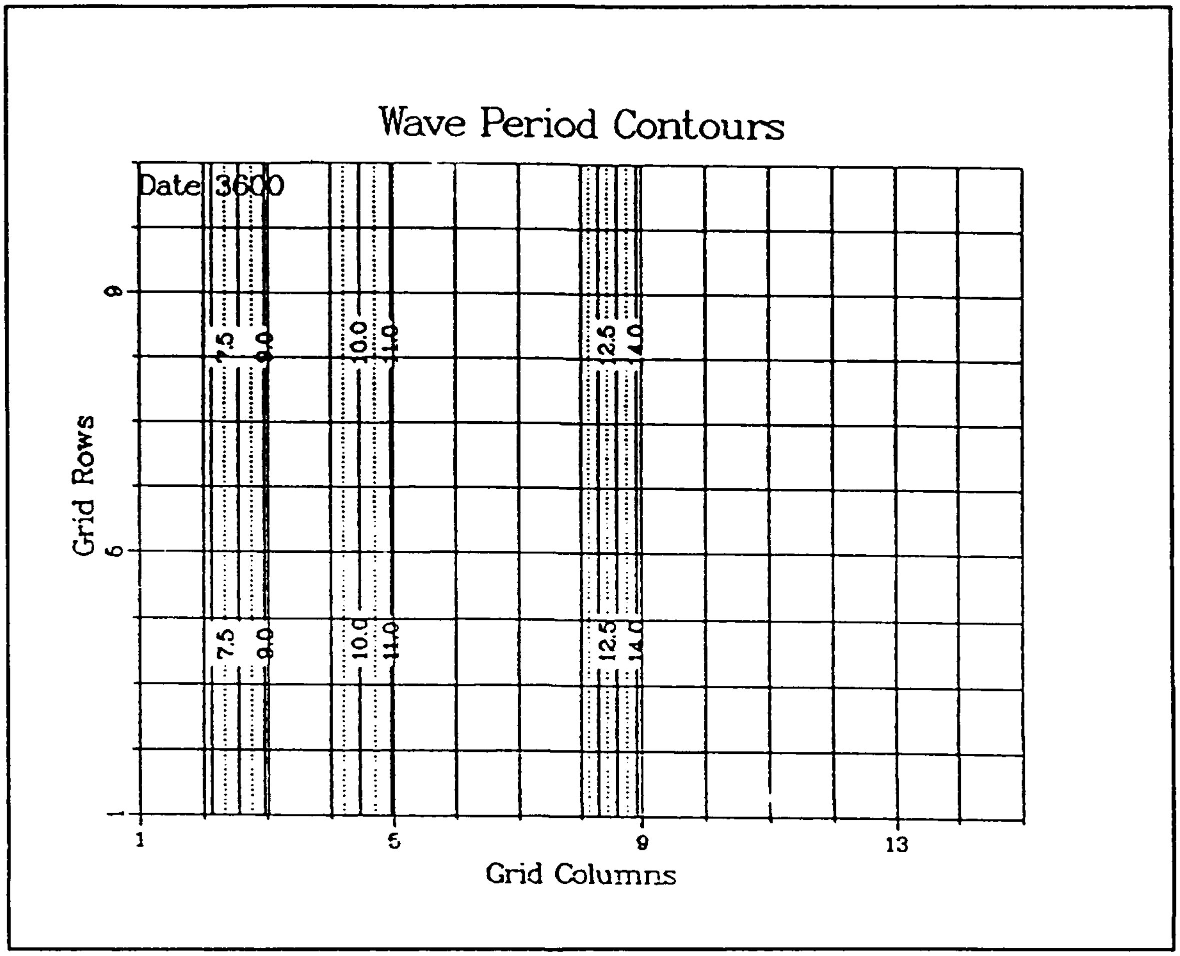


Figure 7-18. Wave period contours for the 36th hr of the example simulation

d. If "Wave History Plots" is selected, you will be required to specify which wave conditions should be plotted. Your choices include the wave conditions for both the wind-sea and swell waves combined, wave conditions for just the wind-sea portion of the wave field, and the wave conditions for just the swell portion of the wave field. Enter "1 2 3" to view all three types of wave conditions simultaneously.

e. After a brief pause, a message will be issued indicating that the metafile containing the plots has been generated. Press RETURN, and select the appropriate device-type for viewing the plots on your terminal. At the "Enter Plot Directives" prompt, enter a RETURN. When you are through viewing the plot, you may exit by pressing RETURN. Figure 22 contains plots of the history of wave height, period, and direction computed at station 3 (location 12, 6) for the 36th hour of the 48-hr simulation.

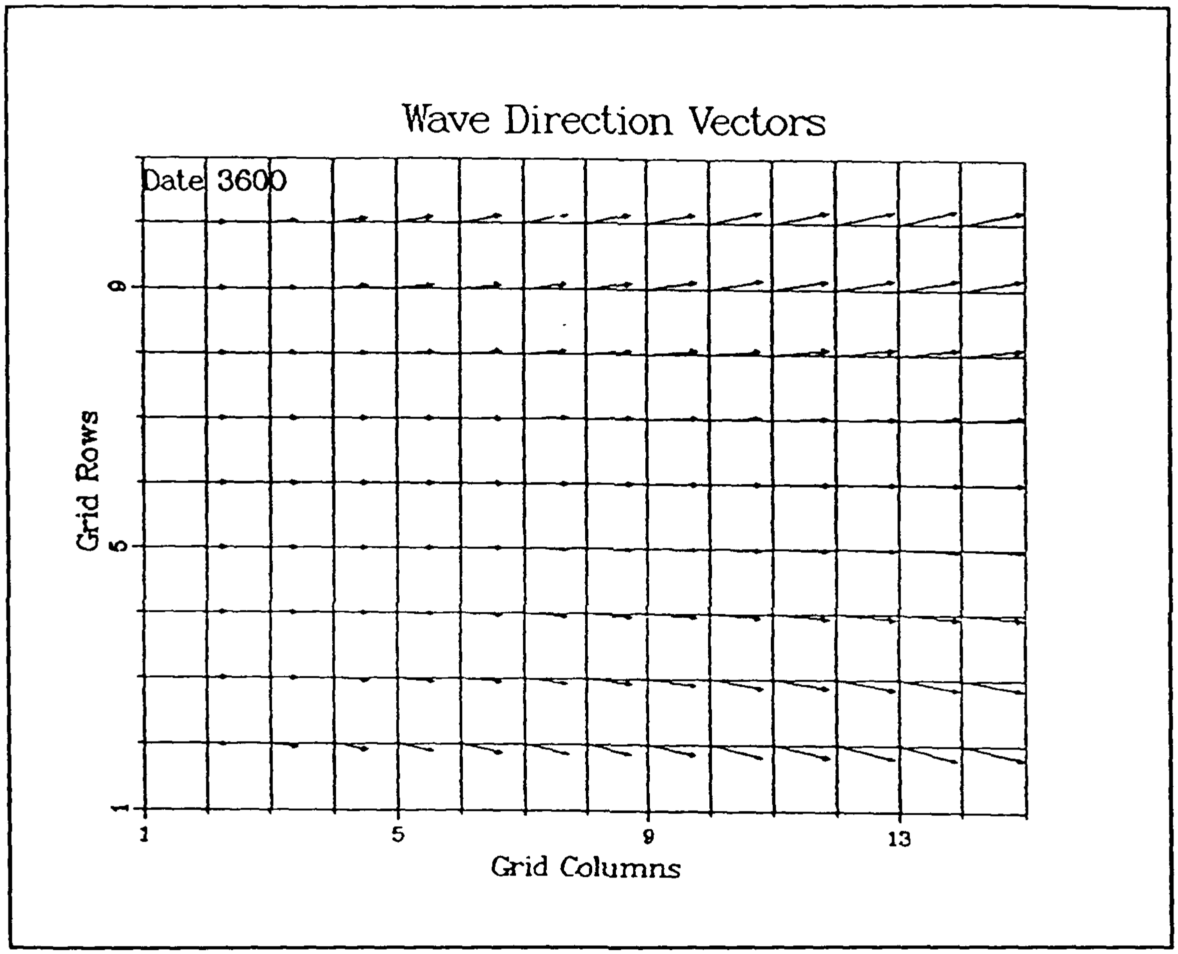


Figure 7-19. Wave direction vectors for the 36th hr of the example simulation

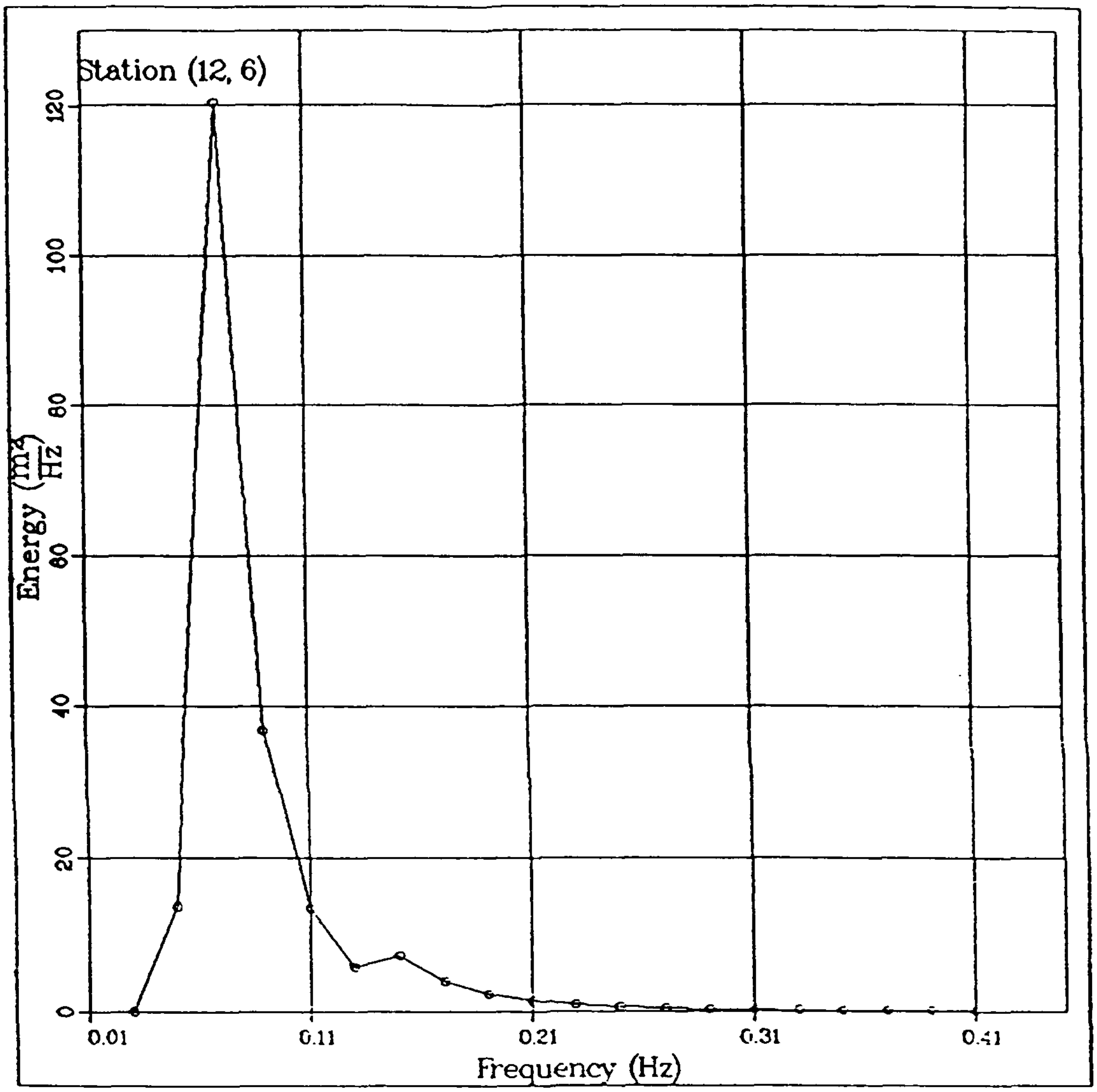


Figure 7-20. One-dimensional wave energy spectrum computed at station 3 for the 36th hr of the example simulation

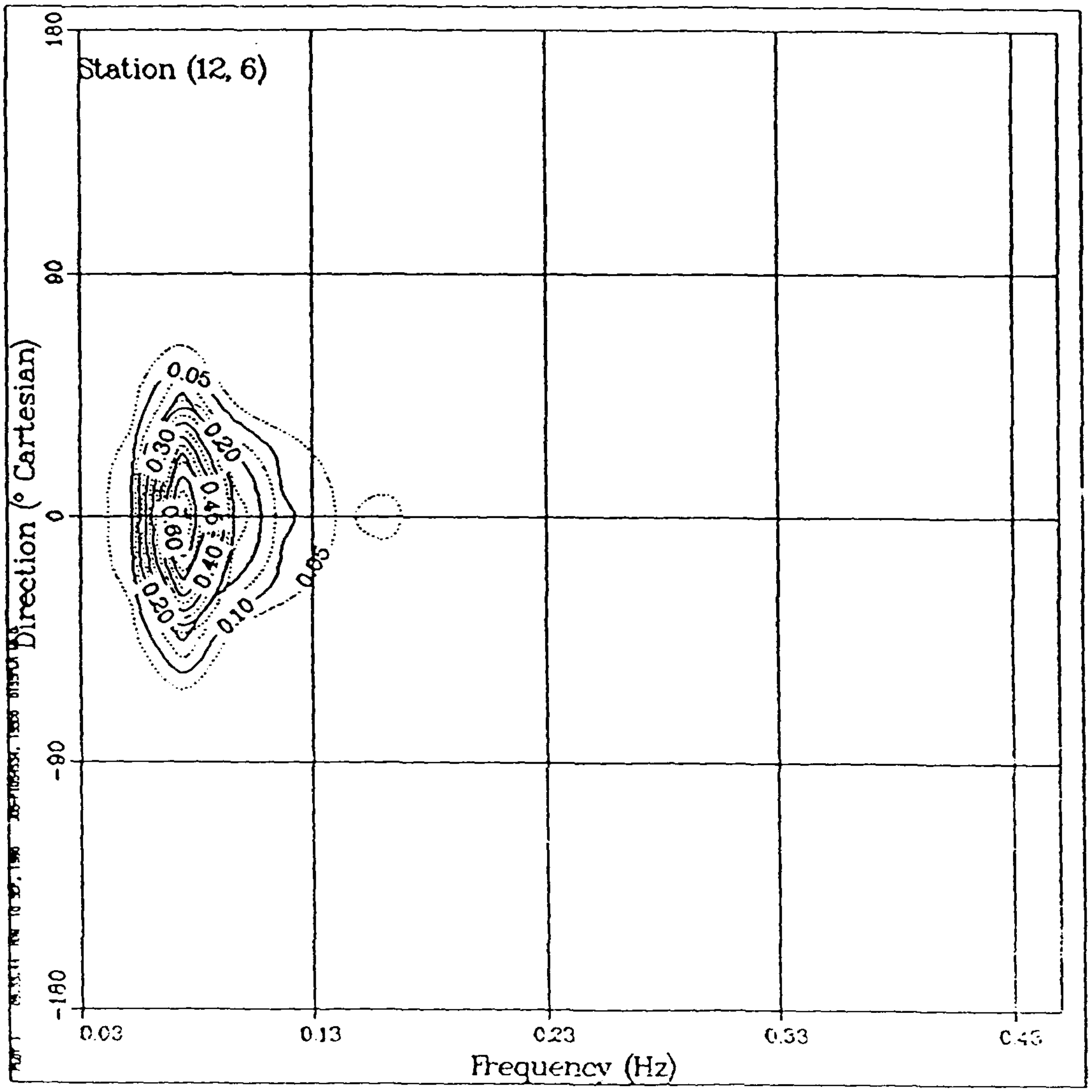


Figure 7-21. Two-dimensional wave energy spectrum computed at station 3 for the 36th hr of the example simulation

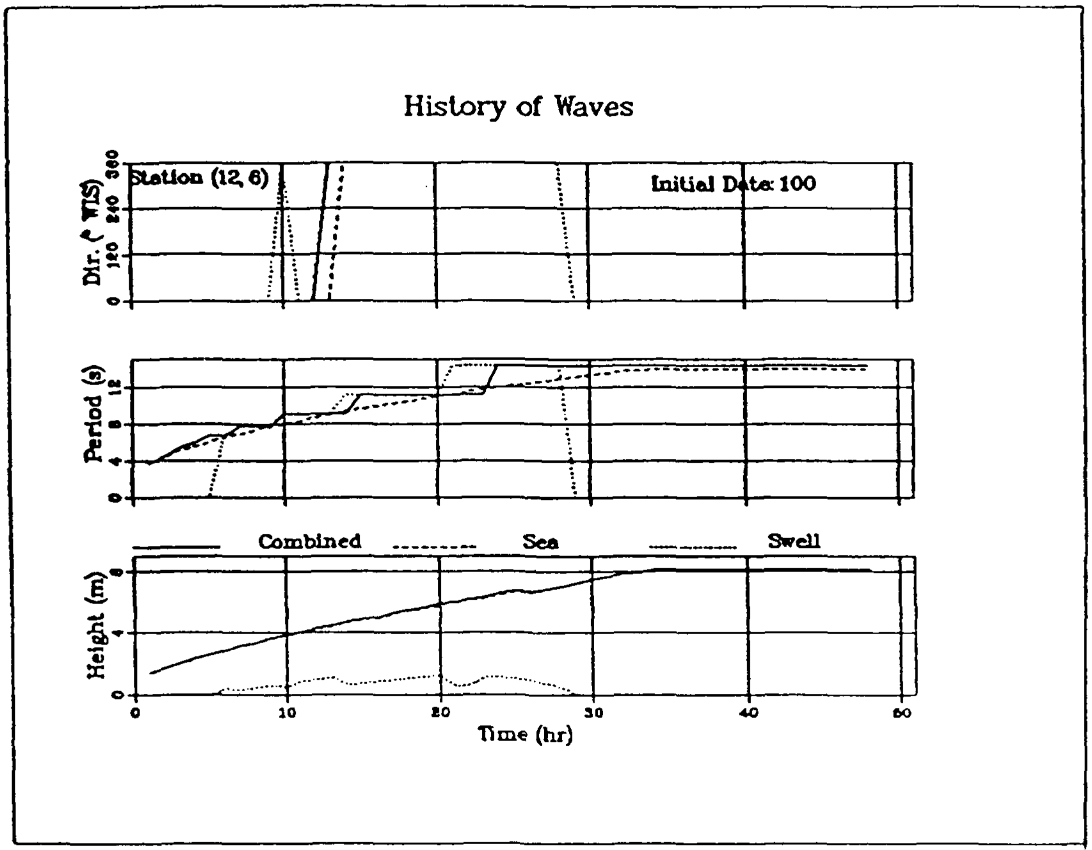


Figure 7-22. History of the wave height, period, and directions computed at station 3

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APPENDIX A: CMSGRID

Introduction

1. Numerical models consist of one or more mathematical equations that define or describe the physical processes of a system. The equations often contain partial derivatives that define how flow field variables change with respect to time and/or space. The models use mathematical (finite difference or finite element) approximations to represent these continuous equations at discrete locations. The continuum is, therefore, represented by discrete points in time and space. Hence, a computational grid is employed by the model to define the flow field at discrete points.

2. A grid is composed of a lattice network of cells, and each cell has certain flow field parameters associated with it. In the case of the WES Implicit Flooding Model (WIFM), these parameters include water depths, water and wind velocities, and water surface elevations. A model is expected to accurately predict flow parameters in the domain of interest, and model accuracy is dependent, in part, on how well the specified grid resolution represents the spatial domain and the flow field. The methodology used to create computational grids for models residing in the Coastal Modeling System (CMS) is presented here.

3. At the present time this package has the capability to generate grids in a stretched rectangular coordinate system. Uniformly spaced grids, which are a subset of this group, can also be generated. The programs contained in this package are listed in Table A-1.

Table A-1

CMSGRID Components

Program	Description
MAPIT	Stretch rectangular coordinate grid generator.
DRAWIT	Graphical program to plot grids generated by MAPIT.
LISTIT	Program to print grid coordinate points.

Computational Technique of Program MAPIT

4. Program MAPIT is designed to calculate the mapping function that relates a variably spaced grid in prototype space to a uniformly spaced grid in computational space. The function defining the mapping from prototype space (x) to computational space (α) is:

$$x = a + b\alpha^c \tag{A1}$$

where

- x = actual mapping distance from the origin
- α = distance from the origin in computational space (which can also be thought of as the cell index number assuming a constant computational grid cell size of 1.0)
- a, b, c = coefficients calculated by the program (Figure A-1)

The entire prototype space to be mapped can be separated into user-specified regions of arbitrary length defined by end points x_1, $x_2 \ldots x_n$ (for n-1 regions), and the mapping function is applied to each region. Values of the three coefficients are thus derived for each of the n-1 regions. The values of a, b, and c are determined by requiring continuity of both the function, x, and its first derivative from region to region. This constraint provides a smoothly varying grid.

5. For any region the following relationships must be satisfied:

$$x_i = a + b\alpha_i^c \tag{A2}$$

$$x_i' = \left(\frac{dx}{d\alpha}\right)_i = bc\alpha_i^{c-1} \tag{A3}$$

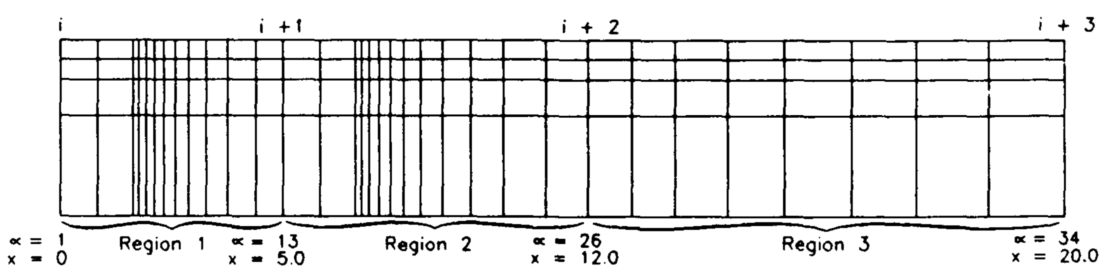


Figure A-1 Variably spaced grid.

$$x_{i+1} = a + b\alpha_{i+1}^{c} \tag{A4}$$

$$x'_{i+1} = \left(\frac{dx}{d\alpha}\right)_{i+1} = bc\alpha_{i+1}^{c-1} \tag{A5}$$

where the subscripts i and $i+1$ refer to the beginning and ending points of the region. The three coefficients (a, b, c) for each region are derived from four nonlinear equations, over-constrained by the known values of x_i , x_{i+1} , x'_i , x'_{i+1} , α_i , and α_{i+1} .

6. In practice, the solution procedure of MAPIT operates somewhat differently. The algorithm assumes that regions are mapped in a sequential order from 1 to $(n-1)$, and that the α's are always positive integers. For any given region, the values of x_i , x'_i , and α_i are known from the computations for the previous region. (The user specifies these values for the first region.) The user specifies the distance to the far end of the region (x_{i+1}) and the cell size at the far end of the region (x'_{i+1}), while the number of cells (α_{i+1}) is computed by the program in a preliminary computation. It should be noted that the value (α_{i+1} - α_i) gives the number of grid cells that lie between the endpoints of a region.

7. Providing that a , b , and c have been determined, an optimal value of α_{i+1} can be chosen, such that the difference between the desired value of x_{i+1} and that calculated from Equation A4 can be minimized. The three coefficients, derived from Equations A2 through A5, are presented below:

$$c = 1 + \frac{\log\ (x'_i/x'_{i+1})}{\log\ (\alpha_i/\alpha_{i+1})} \tag{A6}$$

$$a = x_i - b\alpha_i^c = x_i - \frac{\alpha_i x'_i}{c} \tag{A7}$$

$$b = (x_i - a)/\alpha_i^c \tag{A8}$$

8. This preliminary calculation in MAPIT starts by assuming an α_{i+1} value greater than α_i . The values of a , b , and c are then determined from Equations A6 through A8, and a calculated value of x_{i+1} is obtained from Equation A4. This computed value is compared with the desired value of x_{i+1} ; the value of α_{i+1} is incremented or decremented; and the procedure is repeated until the calculated x_{i+1} value becomes approximately equal to the

desired value. The program warns the user if the region is too small to fit a single cell, or if more than 500 cells appear in any one region. The non-linear system of equations are solved iteratively to assure that a convergent value of the exponent c is generated. Two procedures are used in MAPIT, and they are expressed mathematically below:

$$\textit{Procedure I} \qquad c_{k+1} = \frac{\log\left[\dfrac{(x_{i+1} - x_i)\,c_k}{\alpha_i x_i'} + 1\right]}{\log\,(\alpha_{i+1}/\alpha_i)} \tag{A9}$$

$$\textit{Procedure II} \qquad c_{k+1} = \frac{\alpha_i x_i'}{(x_{i+1} - x_i)}\left[\left(\frac{\alpha_{i+1}}{\alpha_i}\right)^{c_k} - 1\right] \tag{A10}$$

where k is the iteration counter. These two relationships are derived from Equations A2 through A5. Both equations contain one zero root, as well as the root of interest. The roots of interest are then averaged, and the average value of c is used for computing a and b. Procedure I also has an asymptote:

$$c_k = \frac{-\alpha_i x_i'}{x_{i+1} - x_i} \tag{A11}$$

9. Both procedures are solved using the Newton-Raphson method and are compared with each other. All four roots of the two equations are found and checked in order to find problems with pathological solutions for c and poor convergence in iteration. Following the solution for c, the values of a and b are found from Equations A7 and A8. It should be noted that x'_{i+1} is never used in the calculations of the three coefficients computed from Equations A7 through A10. The three coefficients are computed using previously known values of c and the given x_{i+1}. The values of the coefficients satisfy the relationships of Equations A2 through A4, but not Equation A5. MAPIT recalculates x'_{i+1} from Equation A5 to complete the problem, and it displays the results for the region to the user. The user then has the option to continue to the next region, try the same region again with different inputs, or back up to a previous region. If the user does not want the value of x'_{i+1} recalculated by the program, but requires specific

values of both x_{i+1} and x'_{i+1} , then the code can calculate coefficients for two regions at once. The values of x , the derivative, and alpha of the partition point between the two regions are all calculated by the code. The equations for two adjacent regions are:

$$x_i = a_1 + b_1 \alpha_i^{c_1} \tag{A12}$$

$$x_{i+1} = a_1 + b_1 \alpha_{i+1}^{c_1} \tag{A13}$$

$$x_{i+1} = a_2 + b_2 \alpha_{i+1}^{c_2} \tag{A14}$$

$$x_{i+2} = a_2 + b_2 \alpha_{i+2}^{c_2} \tag{A15}$$

$$x'_i = b_1 c_1 \alpha_i^{c_1 - 1} \tag{A16}$$

$$x'_{i+1} = b_1 c_1 \alpha_{i+1}^{c_1 - 1} \tag{A17}$$

$$x'_{i+1} = b_2 c_2 \alpha_{i+1}^{c_2 - 1} \tag{A18}$$

$$x'_{i+2} = b_2 c_2 \alpha_{i+2}^{c_2 - 1} \tag{A19}$$

10. If a value for α_{i+1} is assumed, then this system of equations becomes eight equations with six unknown coefficients, x_i , x_{i+1} , x_{i+2} , x'_i , x'_{i+1} , x'_{i+2} . Equations A12 through A19 can be algebraically reduced to two equations in the unknowns of c_1 and c_2 :

$$x_i + \frac{\alpha_i x'_i}{c_1}\left[\left(\frac{\alpha_{i+1}}{\alpha_i}\right)^{c_1} - 1\right] = x_{i+2} + \frac{\alpha_{i+2} x'_{i+2}}{c_2}\left[\left(\frac{\alpha_{i+1}}{\alpha_{i+2}}\right)^{c_2} - 1\right] \tag{A20}$$

$$x'_i\left(\frac{\alpha_{i+1}}{\alpha_i}\right)^{c_1 - 1} = x'_{i+2}\left(\frac{\alpha_{i+2}}{\alpha_{i+2}}\right)^{c_2 - 1} \tag{A21}$$

These two equations can be manipulated to yield two pairs of equations in c_1 and c_2 :

$$c_1 = 1 + \frac{\log\left[\frac{x'_{i+2}}{x'_i}\left(\frac{\alpha_{i+1}}{\alpha_{i+2}}\right)^{c_2 - 1}\right]}{\log\left(\alpha_{i+1}/\alpha_i\right)} \tag{A22}$$

$$c_2^{k+1} = \frac{\log\left[1 + \frac{c_2^k}{\alpha_{i+2}x'_{i+2}}\left(x_i - x_{i+2} + \frac{\alpha_i x'_i}{c_1}\left[\left(\frac{\alpha_{i+1}}{\alpha_i}\right)^{c_1} - 1\right]\right)\right]}{\log\left(\alpha_{i+1}/\alpha_{i+2}\right)} \tag{A23}$$

$$c_2 = 1 + \frac{\log\left[\frac{x'_i}{x'_{i+2}}\left(\frac{\alpha_{i+1}}{\alpha_i}\right)^{c_1 - 1}\right]}{\log\left(\alpha_{i+1}/\alpha_{i+2}\right)} \tag{A24}$$

$$c_1^{k+1} = \frac{\log\left[1 + \frac{c_1^k}{\alpha_i x_i^i}\left(x_{i+2} - x_i + \frac{\alpha_{i+2} x'_{i+2}}{c_2}\left[\left(\frac{\alpha_{i+1}}{\alpha_{i+2}}\right)^{c_2} - 1\right]\right)\right]}{\log\left(\alpha_{i+1}/\alpha_i\right)} \tag{A25}$$

where the k superscript is an iteration counter. The coefficients c_1 and c_2 can be calculated from either of the above pairs of equations, and the remaining unknowns can be found by substitution.

11. The actual algorithm for the double region routine is rather complicated due to the nature of Equations A22 through A24. Equation A21 represents a straight line with a negative slope in $c_1 - c_2$ space, whereas Equations A23 through A25 each have one asymptote for their dependent variable. These asymptotes are given by:

$$c_1^{k+1} = \frac{\log\left[1 + \frac{c_1^k}{\alpha_i x'_i}\left(x_{i+2} - x_i\right)\right]}{\log\left(\alpha_{i+1}/\alpha_i\right)} \tag{A26}$$

for Equation A23, and

$$c_2^{k+1} = \frac{\log\left[1 + \frac{c_2^k}{\alpha_{i+2} x'_{i+2}}\left(x_i - x_{i+2}\right)\right]}{\log\left(\alpha_{i+1}/\alpha_{i+2}\right)} \tag{A27}$$

for Equation A25.

12. The plot of Equations A21 through A27 is shown in Figure A-2 together with the two possible solution paths suggested by the equation pairs of Equations A22 and A23, and A24 and A25. The major difficulties in the solution algorithm are choosing the appropriate starting values of c_1 and

c_2 and determining which of the two equation pairs yield a convergent solution. Since the asymptotic values of c_1 and c_2 can be determined from Equations A26 and A27, starting values are arbitrarily chosen as a specified percentage of these asymptotic values.

13. In attempting to find a convergent solution, a first estimate is obtained from Equations A22 and A23. If the value of c_2 becomes zero, Equations A24 and A25 are used with the starting values. Should the value of c_1 also become zero, then the starting point lies too close to the asymptotes. A new starting point closer to the origin is then defined, and the whole calculation cycle is repeated. Any time both equation sets are satisfied by a zero solution or fail to converge within a set number of iterations, the starting point is redefined, and the iteration procedure is repeated. Calculations cease after 10 different starting points have been tried, and the user is warned about nonconvergence of the input values.

14. It must be pointed out that not every possible set of inputs for the double region routine will yield a solution. The algorithm is coded to make a reasonable attempt to find a solution; however, the user is warned about nonconvergent cases or pathological functions. The procedure also attempts to resolve other problems, such as attempts to take the logarithm of negative numbers.

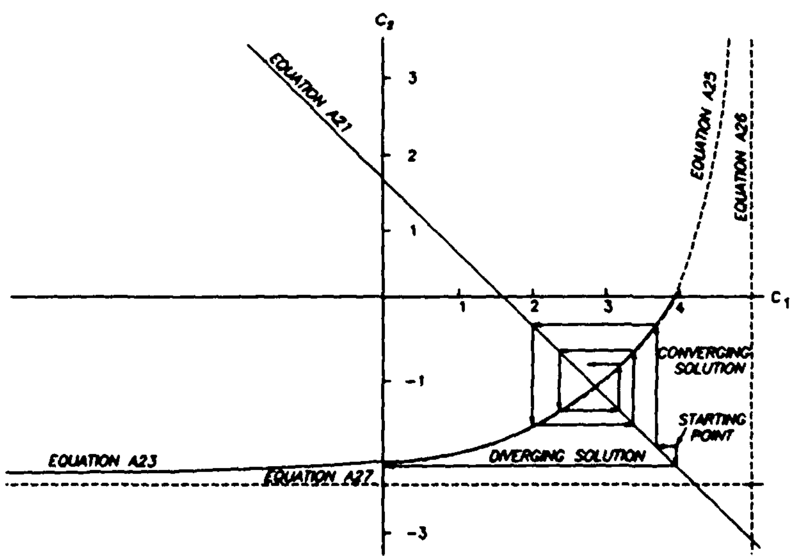


Figure A-2 Graphic solution of double region procedure

Generating Stretch Rectilinear Grids

15. Three basic steps are required to generate stretched rectilinear grids:

   a. Defining the grid orientation and limits.

   b. Determining the grid cell resolution in the seaward direction.

   c. Determining the grid cell resolution in the longshore direction.

16. The following discussion presents guidelines for the above topics; however, due to the complexity of coastal regions, these guidelines will not be applicable to every situation encountered. Hence, knowledge of the capabilities and limitations of the model intended to be used is needed in developing computational grids.

Grid orientation and limits

17. The user should select a detailed chart or map of the study area with sufficient resolution of the coastline and hydraulic features to resolve such features as sharp depth gradients or reefs. Maps constructed from a Mercator projection should be used, especially if multiple maps are needed to define the study area. Mercator projection preserves the angle relationship, allowing the grid to be transferred from one scale to another without distortion.

18. The user should overlay the map with a sheet of Mylar or tracing paper and draw a line on the Mylar that best describes the coastline orientation along the reach that is of primary interest. A line perpendicular to any inlet or channel of interest should be drawn. These lines provide guidance concerning orientation of grid axes.

19. The x and y axes can be oriented arbitrarily as long as a right-handed coordinate system is used. However, the choice of alignment for the grid axes is extremely important, especially when the geometric features of the area to be modeled are complex. Because the modeled area must be represented with rectangular cells, the user should keep in mind that minimizing any stair-stepped representation of shorelines, structures, and/or major channels will produce the most suitable grid.

20. For WIFM simulations, the user should estimate the maximum flood height resulting from extreme tidal- or storm-induced water levels that will be simulated by the model. This estimate can usually be supplied from

historical records; if not, approximate values can be computed by the procedures presented in EM 1110-2-1412. Next, a freeboard of at least 3 ft should be added to the maximum flood height. The user then locates points or line segments delineating the extent of flooding and uses these points to define the boundaries of the grid. Topographic features that prevent flooding should also be considered when defining the model domain.

21. For a storm surge simulation, the seaward boundary should extend to the seaward edge of the Continental Shelf. Therefore, the user should draw another line on the Mylar parallel to the reference line, at the Continental Shelf. The adjacent, or lateral, boundaries must be placed far enough from the area of interest so that inaccuracies caused by uncertainties in the boundary values specified in the model are minimized. As a rule of thumb, the grid should extend laterally from the area of interest in each direction, a distance of at least 1.5 to 2.0 times the distance from the coastline to the shelf.

22. For a tidal circulation investigation, the grid limits are dependent on the size and shape of the area of interest and where data are available for establishing a proper boundary condition. For example, back-bay areas in the model may be influenced by river/channel systems. The model grid should extend into such systems to a point where the water level, flow rate, or velocity have been measured and can be used to establish a boundary condition. In the open coast area, the seaward and lateral open boundaries should extend far enough from the area of interest so that computations in the area of interest are not significantly affected by inaccuracies in boundary specification. Again, data (usually water level measurements or tidal constituents) should be available in the open coastal area to be used as boundary conditions.

23. Many WIFM applications involve consideration of tidal hydrodynamics at structured inlets. A general rule of thumb is to locate open water boundaries a distance from the inlet equivalent to 5 times the length of the inlet structure.

24. In storm or tidal investigations, a grid sensitivity study can be performed. This type of test is usually performed to minimize the size of the open ocean portion of a grid. The test is done by first developing a grid with limits exceeding the specifications mentioned in earlier paragraphs. Having made good engineering estimates for other model input parameters

(depth, friction, etc.), a test is run with the large grid. The test is then repeated after reducing the grid size in both seaward and lateral directions. The results in the area of interest are checked to determine the impact of the new boundary location.

Seaward grid cell resolution

25. A profile of the seabed is drawn on a separate sheet of Mylar, running from the onshore boundary to the seaward boundary. The bottom profile is simplified by drawing straight lines that represent regions having approximately the same slope. (Normally four to eight regions are sufficient.) A separate stretching function (Equation A2) should be applied to each region in order to generate grid cells that adequately define the area. As a first attempt at creating a grid, a constant value of the ratio, $\Delta x/L$, (where Δx is the grid cell size and L is the wavelength) should be maintained.

26. Cell dimensions are first chosen for the area of interest. In this region the cells should be square, or nearly square, and have a greater resolution (i.e., more cells per unit area) than in the remaining regions. Cell sizes must be small enough so that the hydraulic features are resolved. However, computer costs for executing the model will be prohibitive if the grid has too many cells or if the minimum cell size forces the choice of a very small time-step according to the Courant stability constraint.

27. Seaward of the area of interest, cell dimensions can usually be increased. This is performed by smoothly increasing cell dimension sizes over the distance defined by the slope region. The first cell in a region should not increase by more than 25 percent of the size of the last cell in the previous region. The largest cell in the grid, normally located at the seaward boundary, should not be greater than 20 times the size of the smallest cell in the grid.

28. Grid sizes may increase in the inland direction away from the area of interest. However, care should be taken to sufficiently resolve the inland water/land system. Proper resolution will ensure the flooding and drying algorithm in model WIFM can be accurately applied to this area.

Longshore grid cell resolution

29. Longshore grid cell resolution is determined from the variability of the coastline as opposed to bed slope in the seaward direction. However, the concepts of increasing the resolution in areas of rapid change are the

same. Greater resolution is needed in areas where the landforms or other hydraulic features have significant influence on hydrodynamics in the region of interest. Grid lines should be placed to match the orientation of these features, where possible.

30. As a practical guideline, there are two basic methods for ensuring good grid resolution of small hydraulic features such as inlets. The first method is to put a partition in the middle of the inlet. If a suitably small cell width is chosen for this partition, with larger cell sizes at the two nearest endpoints, then the inlet will be modeled with a cell group smallest in the center of the inlet and largest at its edges. If a relatively constant cell size is desired across an inlet, then it is best to place a partition point at each edge of the inlet, so that the inlet becomes one region. Equal cell widths can be defined at the end points, resulting in nearly constant cell widths across the inlet. This method has the advantages of placing partition lines at the land-water boundaries of the inlet and ensuring a specific grid resolution; however, this often generates a larger number of cells over the entire grid because the fine resolution in the inlet will be "carried" into the open ocean area.

31. For featureless terrain bounded by high-resolution regions, two partitioning methods can be used to minimize the number of required grid cells. One method divides the area into two regions, containing partitions with small cells in the required areas. The second method divides the area into three regions, with small cells at the outer partitions and large cells at the two inner partitions. This method creates large cells in the middle region and rapid changes in cell size in the two outer regions of the area. The method that produces the minimum number of cells is preferable.

Additional considerations for grid generation

32. As a practical guideline, channels should be oriented approximately parallel to the grid axes to avoid stair-stepping. Orientation at a 45-degree angle for square grid cells would maximize stair-stepping and should be avoided. Another method of avoiding stair-stepping is to alter the orientation of water bodies in nonsensitive areas while preserving storage capacity, as shown in Figure A-3.

33. The ratio of the cell size in the longshore direction to the cell size in the on-offshore direction, or aspect ratio, should also be examined and considered when generating a grid. For example, model RCPWAVE requires

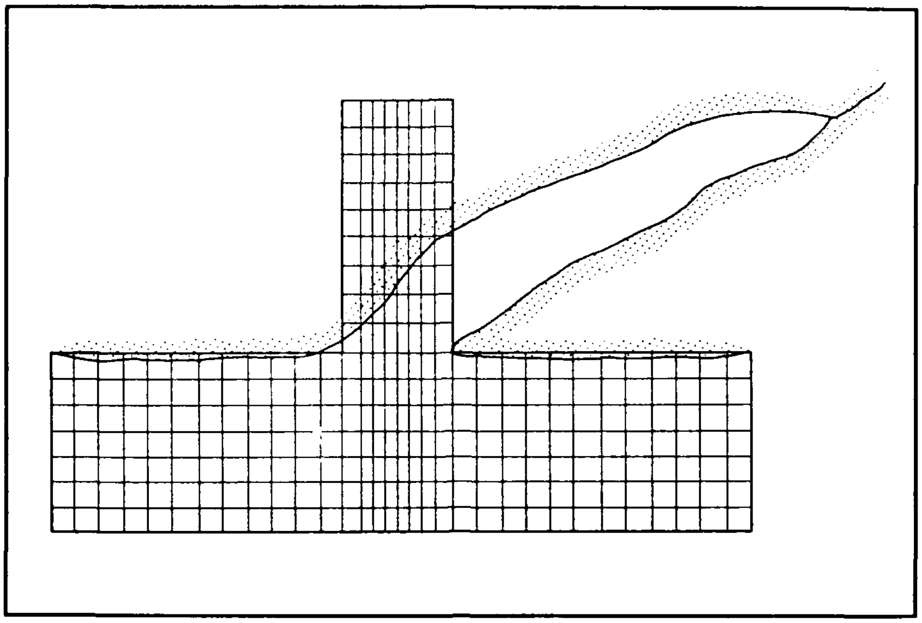


Figure A-3. Altered representation of a water body

large aspect ratios to resolve large input wave angles. An aspect ratio of two is typically used for RCPWAVE applications. On the other hand, hydrodynamic models, such as WIFM and CLHYD, produce most accurate results with an aspect ratio of 1, indicating "square" grid cells. An aspect ratio within the range 0.2 and 5 produces adequate results in the area of interest and the aspect ratio can be as much as 20 away from the area of interest.

34. Lastly, the user should be aware of the implications of two stability criteria on grid generation, the Courant condition and the diffusion number. The Courant condition

$$C_r = \frac{\sqrt{gH}}{\Delta x / \Delta t}$$

defines the maximum permissible time-step size for a given value of C_r, where g is the gravitational acceleration, Δx is the dimension of the smallest grid cell within the computational domain, H is the depth at that cell, and Δt is the time-step size. Therefore, a fine-resolution grid will require a small time-step size and a large number of time-steps for a given simulation length, which can become computation prohibitive. The Courant number, C_r, is ideally less than 0.5, but results can be obtained for C_r

less than 7.0. It is recommended that a Courant number on the order of 1.0 to 7.0 be used for WIFM and CLHYD applications.

35. The second stability criterion, the advection limit, is the maximum allowable time-step, Δt , based on the time for a particle to travel through the smallest grid cell:

$$\Delta t \leq \frac{\Delta x}{U} \text{ or } \frac{\Delta y}{V}$$

where Δx and Δy are the smallest grid cells in the x- and y- directions, respectively and U and V are the particle velocities in the x- and y-directions, respectively. Experienced modelers usually select a time-step *somewhat* "less than" this limit, rather than "equal to" the limiting value.

Program MAPIT

36. Program MAPIT generates computational grids for the models residing in CMS. Presently, this program will generate only grids having stretched or uniform rectilinear coordinate systems (i.e., models WIFM, SPH, RCPWAVE, CLHYD, and SHALWV). Guidelines for developing a stretched rectilinear grid have been discussed previously in this Appendix.

37. Computer costs incurred in executing the models can be reduced by selecting the x-direction axis so that it contains more grid cells than the y-axis. Cost reduction is related to the manner in which two-dimensional arrays are stored. The x- and y-direction grid axes can be computed, or mapped, in either order; however, the following requirements must be met:

- a. Each region must be mapped in sequence, starting at the axis origin.
- b. Distances are measured from the axis origin. A common choice for distance units is map inches so a map overlay can be created.
- c. Grid cells are numbered sequentially, with the first cell at the axis origin.

Program input data

38. Program MAPIT is executed interactively. Hence, the program will prompt the user for the input data. *MAPIT responses require capital letters.* An instruction menu, listing the valid user commands and corresponding variables, is presented in Table A-2.

Table A-2

Instruction Menu for Program MAPIT

Command	Input Data	Defaults	Description
?			Invokes the HELP utility that lists valid user responses.
SINGLE	X2 X2P	none	SINGLE region mapping. X2 - distance from origin to far end of region. X2P - cell width at last cell in region.
DOUBLE	X3 X3P L3 L2	none	DOUBLE region mapping. X3 - distance to far end of region partition. X3P - cell width of last cell in region. L3 - cell number of last cell in region. L2 - cell number of cell at center of region.
BACKUP	IREG	none	Recompute region mapping IREG - region number to be remapped.
SUMMARY		none	Produces a summary of all mapping previously performed.
ENDDIR		none	Ends mapping direction.
DEBUG	"ON" "OFF"	"OFF"	Prints diagnostics and intermediate computations.

39. A SINGLE command specifies a region composed of one stretching function. Variable X2 defines the distance from the axis origin to the far edge, or partition, of the region. Variable X2P defines the grid cell width at the far edge.

40. A DOUBLE command specifies a region composed of two stretching functions. Variable X3 defines the distance from the axis origin to the far edge, or partition of the region, and variable X3P is the width of the last cell in that region. The user must also specify the cell number at the far edge of the region (variable L3) and the cell number at the center of the region (variable L2).

41. The solution algorithm in program MAPIT will diverge if improper values are entered for a region. If the solution does diverge, convergence can normally be achieved by adjusting the values for variables X3P and/or L2. Additional information concerning the divergence/convergence of the computational algorithm is discussed in the section titled "Computational Technique of Program MAPIT."

42. An option is included in program MAPIT to allow the user to recompute regions (option BACKUP). However, all regions mapped subsequent to the initial attempt of a remapped region will be deleted.

43. Mapping is terminated by entering the ENDDIR command. The user is then prompted to map the remaining direction or terminate the mapping session.

Program execution

44. The program will prompt the user for:

a. A mapping direction (either x- or y-axis).

b. The initial distance to the grid origin (x) which is usually set to 0.0.

c. The initial grid cell index number (ALPHA), which is usually set to 1.

d. Initial cell width.

45. The interactive session begins by entering the command:

```
h2crplcl:larry$/u3/h2crplc0/cms
```

on the CRAY Y-YMP supercomputer located at WES (see Chapter 2). It should be noted that user entries are shown as shaded and the CMS response "screens" are shaded boxes.

The CMS responds:

```
               W E L C O M E   T O . . .

         XXXXX          X     X          XXXXX
        X     X         XX   XX         X     X
        X               X X X X         X
        X               X  X  X          XXXXX
        X               X     X               X
        X     X         X     X         X     X
         XXXXX          X     X          XXXXX


                    Return for more...
```

```
**********************************************************************
*                          C M S   COMPONENTS                        *
*--------------------------------------------------------------------*
*  Options:                                                          *
*                                                                    *
*  CMSGRID (Maps, plots, and lists the numerical grid)  ------>  1   *
*                                                                    *
*  CMSMODEL (Compiles, links, loads, and executes                    *
*                 numerical models)  ------------------------>  2    *
*                                                                    *
*  CMSPOST (Plots and lists model outputs)  ------------------>  3   *
*                                                                    *
*  CMSUTIL (Additional "utility" programs)  ------------------>  4   *
*                                                                    *
*  Exit CMS  ------------------------------------------------->  e   *
**********************************************************************
```

```
Enter option number  ------------------------->  1
```

The CMS responds:

```
   CCCC       M     M     SSSS       GGGG      RRRRR     I    DDDDD
  C    C      MM   MM    S    S     G    G     R    R    I    D    D
 C            M M M M    S         G           R    R    I    D     D
 C            M  M  M     SSSS     G           RRRRR     I    D     D
 C            M     M         S    G   GGG     R  R      I    D     D
  C    C      M     M    S    S     G    G     R   R     I    D    D
   CCCC       M     M     SSSS       GGGG      R    R    I    DDDDD



                       Return for more...
```

```
*********************************************************************
*                                                                   *
*                 USING THE COASTAL MODELING SYSTEM                 *
*                                                                   *
*********************************************************************
*                                                                   *
*  Options:                                                         *
*                                                                   *
*    On-Line Help ------------------------------------------> 1     *
*                                                                   *
*    Enter CMSGRID Module ----------------------------------> 2     *
*                                                                   *
*    Return to Main Menu -----------------------------------> 3     *
*                                                                   *
*********************************************************************
```

```
Enter option number -----------------> 2
```

```
************************************************************
*                    CMSGRID COMPONENTS                    *
************************************************************
*   MAPIT: (Stretched/constant rectangular                 *
*           coordinate grid generator)  -------------> 1 *
*                                                          *
*   DRAWIT:    (Graphical program to plot grids            *
*           generated by MAPIT)  ------------------> 2 *
*                                                          *
*   LISTIT:    (Program to print grid coordinate           *
*           points)  -----------------------------> 3 *
*                                                          *
*   EXIT:  (Terminate computer session)  ------------> 4  *
************************************************************
```

The user is prompted to select a CMSGRID component:

Enter option number -------------------> **1**

The CMS responds:

```
  X       X        X      XXXXXX     XXXXXXX   XXXXXXX
  XX     XX       X X     X     X       X         X
  X X   X X      X   X    X     X       X         X
  X  X X  X     XXXXXXX   XXXXXX        X         X
  X   X   X     X     X   X             X         X
  X       X     X     X   X             X         X
  X       X     X     X   X          XXXXXXX      X


                   Return for more...
```

The user is prompted to provide a name for the output file which will contain the grid stretching coefficients:

Enter output file name **2area2.map**

The user is prompted to select a mapping direction:

```
SPECIFY MAPPING DIRECTION (X OR Y):
NOTE:  REGIONS MUST BE MAPPED IN SEQUENCE...
X
```

The user is prompted for an initial distance for the grid origin (x) and an initial grid cell index number (ALPHA):

```
SPECIFY INITIAL X DISTANCE AND ALPHA
(CARRIAGE RETURN EMPLOYS DEFAULTS: X=0.0 AND ALPHA=1)
*** USE ONLY INTEGERS FOR ALL ALPHAS INPUT!!!
0.0 1
```

The user is prompted for an initial cell size (x'):

```
SPECIFY ASSOCIATED DERIVATIVE X-PRIME:
1.
```

The user may now chose to display a menu of valid commands:

```
CHOOSE AN INSTRUCTION FROM THE MENU:
   ...MAY BE ABBREV TO FIRST 3 CHAR...
   ...ENTER "MENU" OR "?" TO SEE MENU...
   ...PLEASE USE UPPERCASE...
?
```

The program responds:

INSTRUCTION MENU FOR PROGRAM MAPIT:

KEYWORD:	INPUT DATA:	DEFAULTS:	KEYWORD FUNCTION:
MENU			PRINTS THIS MENU
SINGLE	X2 X2P	NONE	SINGLE REGION MAPPING
DOUBLE	X3 X3P AL3 AL2	NONE	DOUBLE REGION MAPPING
BACKUP	REG	CURRENT REG	BACK UP/REDO REGION (REG=0 RESTARTS DIR)
SUMMARY			SUMMARIZES MAPPING WORK DONE SO FAR
ENDDIR			ENDS THIS MAPPING DIRECTION AND SAVES DATA
DEBUG	"ON" OR "OFF"	"OFF"	PRINTING SWITCH FOR PROGRAM DEBUGGING

AN EXPLANATION OF THE INPUT DATA:

```
X2  - DISTANCE AT RIGHT SIDE OF A SINGLE REGION
X2P - SLOPE (X-PRIME) AT RIGHT SIDE OF A SINGLE REGION
X3  - DISTANCE AT FAR END OF THE SECOND REGION
X3P - SLOPE (X-PRIME) AT FAR END OF THE SECOND REGION
AL3 - ALPHA AT FAR END OF THE SECOND REGION
AL2 - ALPHA AT THE MIDDLE REGION LINE OF A DOUBLE REGION
REG - THE REGION NUMBER YOU WISH TO REMAP
      (NOTE ALL MAPPING COMPUTATIONS AFTER THIS REGION ARE
      WRITTEN OVER AND WIPED OUT)
```

The user selects a single region 15 units long with an ending cell size of 1 unit:

```
CHOOSE AN INSTRUCTION FROM THE MENU:
   ...MAY BE ABBREV TO FIRST 3 CHAR...
   ...ENTER "MENU" OR "?" TO SEE MENU...
   ...PLEASE USE UPPERCASE...
SINGLE 15. 1.
```

Since the initial cell size (x') was 1 unit, then the cells for this region are a constant value of 1 unit. The program responds:

```
          FOR REGION     1
    X1 -   0.00000      ALPHA1 -  1       X1 PRIME -  1.00000000
    X2 -  15.00000      ALPHA2 -  16      GIVEN X2 PRIME -  1.00000000
X2CALC -  15.00000                         CALC X2 PRIME -  1.00000000

         A - -.100000000000000000E+01
         B - 0.100000000000000000E+01
         C - 0.100000000000000000E+01
```

The user selects a single region ending 25 units from the origin with an ending cell size of 0.5 units:

```
CHOOSE AN INSTRUCTION FROM THE MENU:
   ...MAY BE ABBREV TO FIRST 3 CHAR...
   ...ENTER "MENU" OR "?" TO SEE MENU...
   ...PLEASE USE UPPERCASE...
SINGLE 25. .5
```

The program responds:

```
          FOR REGION     1
    X1 -  15.00000      ALPHA1 -  16            X1 PRIME -  1.000000000
    X2 -  25.00000      ALPHA2 -  30      GIVEN X2 PRIME -  1.000000000
X2CALC -  24.74005                         CALC X2 PRIME -  0.52722165


         A - 0.887645621036801458E+03
         B - -.918153961332387552E+03
          C - -.183350487463515010E-01
```

The user has completed mapping the x-direction:

```
CHOOSE AN INSTRUCTION FROM THE MENU:
    ...MAY BE ABBREV TO FIRST 3 CHAR...
    ...ENTER "MENU" OR "?" TO SEE MENU...
    ...PLEASE USE UPPERCASE...
END
```

The program responds:

X-DIRECTION MAPPING COMPLETE: 2 REGIONS

REG	X-SPACE		ALPHA		X-PRIME		A	B	C
	FROM	TO	FROM	TO	FROM	TO			
1	0.0000	15.0000	1	16	1.000	1.000	-1.000	1.000	1.000
2	15.0000	25.0000	16	30	1.000	0.527	887.6	-918.2	-.1834E-01

The user selects to map another direction:

```
MAPPING IN THE X DIRECTION IS COMPLETED
DO YOU WISH TO MAP IN ANOTHER DIRECTION (Y/N)?
Y
```

The user specifies which direction to map:

```
SPECIFY MAPPING DIRECTION (X OR Y):
Y
```

The user is prompted for an initial distance from the grid origin (Y) and an initial cell size (ALPHA):

```
SPECIFY INITIAL Y DISTANCE AND ALPHA
(CARRIAGE RETURN EMPLOYS DEFAULTS: Y=0.0 AND ALPHA=1)
*** USE ONLY INTEGERS FOR ALL ALPHAS INPUT!!!

0.0 1
```

The user is prompted for an initial cell size (Y'):

```
SPECIFY ASSOCIATED DERIVATIVE Y-PRIME:
1.
```

The user selects a single region 15 inches in length with a cell size of 1 inch:

```
CHOOSE AN INSTRUCTION FORM THE MENU:
   ...MAY BE ABBREV TO FIRST 3 CHAR...
   ...ENTER "MENU" OR "?" TO SEE MENU...
   ...PLEASE USE UPPERCASE...
SINGLE 15. 1.
```

Since the initial cell size (Y') was 1 inch, then the cells for this region are a constant value of 1 inch. The program responds:

```
          FOR REGION    1
      Y1 =   0.00000       ALPHA1 =   1           Y1 PRIME =  1.00000000
      Y2 =  15.00000       ALPHA2 =  16     GIVEN Y2 PRIME =  1.00000000
  Y2CALC =  15.00000                         CALC Y2 PRIME =  1.00000000

         A = -.100000000000000000E+01
         B = 0.100000000000000000E+01
         C = 0.100000000000000000E+01
```

The user has completed mapping the y-direction:

```
CHOOSE AN INSTRUCTION FROM THE MENU:
   ...MAY BE ABBREV TO FIRST 3 CHAR...
   ...ENTER "MENU" OR "?" TO SEE MENU...
   ...PLEASE USE UPPERCASE...

END
```

The program responds:

```
Y-DIRECTION MAPPING COMPLETE:    1 REGIONS

 REG      Y-SPACE          ALPHA        Y-PRIME         A          B          C
      FROM       TO      FROM   TO    FROM    TO
   1  0.0000  15.0000      1    16    1.000  1.000  -1.000      1.000      1.000

 MAPPING IN THE Y DIRECTION IS COMPLETED
 DO YOU WISH TO MAP IN ANOTHER DIRECTION (Y/N)?
 N
```

The system responds:

```
STOP
CP:  0.010s,   Wallclock:  70.114s

*** END OF CMSGRID PROCEDURE ***
```

Program output

46. Output of program MAPIT consists of a file containing the XSTRETCH and YSTRETCH records used by models WIFM and SPH. These records can be directly added to those models' input data files. Furthermore, this file can be processed using programs LISTIT and DRAWIT, which are discussed in the following sections.

Program DRAWIT

47. Program DRAWIT is an interactive program for graphically displaying and/or plotting the computational grid produced by program MAPIT. Hence, program MAPIT must be executed first to develop the grid stretching coefficients. In addition, bathymetric data can be plotted directly on the computational grid, if such data are available in a computer file in the format shown below:

```
BATHSPEC       FEET      0.0     0.0      -10.0     XY     (9F8.2)
-10.00  -10.00  -10.00  -10.00  -10.00  -10.00  -10.00  -10.00  -10.00  -10.00
-10.00  -10.00  -10.00  -10.00  -10.00  -10.00  -10.00  -10.00  -10.00  -10.00
-10.00  -10.00  -10.00  -10.00  -10.00  -10.00  -10.00  -10.00  -10.00  -10.00
. . .
```

48. Program DRAWIT presently can generate graphical output for the following devices:

a. Tektronix 4014 terminals, DEC VT series terminals, or compatible devices.

b. Hewlett Packard DraftMaster II drum plotters or compatible devices.

49. A drum plotter is typically used for producing map overlays. These overlays are very helpful when developing input bathymetry/topography data set for models such as WIFM. Presently, the map overlays can be plotted at the Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC) or Information Technology Laboratory (ITL). The user may wish to contact their ADP coordinator to determine whether a plot file can be plotted on in-house devices.

Program execution

50. The interactive session begins by entering the command:

```
h2crplcl:larry$/u3/h2crplc0/cms
```

The CMS responds:

```
        W E L C O M E   T O . . .

      XXXXX        X     X       XXXXX
     X     X       XX   XX      X     X
     X             X X X X      X
     X             X  X  X       XXXXX
     X             X     X            X
     X     X       X     X      X     X
      XXXXX        X     X       XXXXX


            Return for more...
```

```
*********************************************************************
*                         C M S   COMPONENTS                        *
*-------------------------------------------------------------------*
*  Options:                                                         *
*                                                                   *
*  CMSGRID (Maps, plots, and lists the numerical grid)  ------> 1  *
*                                                                   *
*  CMSMODEL (Compiles, links, loads, and executes                   *
*                 numerical models) ----------------------> 2  *
*                                                                   *
*  CMSPOST (Plots and lists model outputs)  ----------------> 3  *
*                                                                   *
*  CMSUTIL (Additional "utility" programs)  ----------------> 4  *
*                                                                   *
*  Exit CMS  -------------------------------------------------> e  *
*********************************************************************
```

```
Enter option number  ------------------------> 1
```

```
The CMS responds:
```

```
  CCCC      M     M     SSSS      GGGG     RRRRR     I    DDDDD
 C    C     MM   MM    S    S    G    G    R    R    I    D    D
C           M M M M    S        G          R    R    I    D     D
C           M  M  M     SSSS    G          RRRRR     I    D     D
C           M     M         S   G   GGG    R  R      I    D     D
 C    C     M     M    S    S    G    G    R   R     I    D    D
  CCCC      M     M     SSSS      GGGG     R    R    I    DDDDD


                      Return for more...
```

```
*********************************************************************
*                                                                   *
*                USING THE COASTAL MODELING SYSTEM                  *
*                                                                   *
*********************************************************************
*                                                                   *
*  Options:                                                         *
*                                                                   *
*    On-Line Help ------------------------------------------->  1   *
*                                                                   *
*    Enter CMSGRID Module ---------------------------------->  2   *
*                                                                   *
*    Return to Main Menu ----------------------------------->  3   *
*                                                                   *
*********************************************************************
```

```
Enter option number ------------------> 2
```

```
*************************************************************
*                   CMSGRID COMPONENTS                      *
*************************************************************
*  MAPIT: (Stretched/constant rectangular                  *
*           coordinate grid generator) -------------> 1 *
*                                                           *
*  DRAWIT:    (Graphical program to plot grids
              *
*           generated by MAPIT) --------------------> 2 *
*                                                           *
*  LISTIT:    (Program to print grid coordinate
*
*           points) ---------------------------------> 3 *
*                                                           *
```

The user is prompted to select a CMSGRID component:

Enter option number ------------------> **2**

The CMS responds:

```
DDDDDD        RRRRR        A       W     W    IIIIIII   TTTTTTT
D    D        R   R       A A      W     W       I         T
D     D       R   R      A   A     W     W       I         T
D     D       RRRRR      AAAAAAA   W  W  W       I         T
D     D       R R        A     A   W W W W       I         T
D    D        R  R       A     A   WW   WW       I         T
DDDDDD        R   R      A     A   W     W    IIIIIII      T



                      Return for more...
```

The user is prompted for the file name generated by MAPIT containing grid stretching coefficients:

Enter name of the input data set **2area2.map**

The user is prompted for bathymetric data if they exist:

```
Do you want to plot bathymetric data on the grid
N
```

The program responds:

```
     CURRENT PLOT FEATURE SUMMARY:
   INDEX DIRECTION:  ----X-----  ----Y-----
 NO. OF GRID CELLS:    1 TO  29    1 TO  15
    CURRENT WINDOW:    1 TO  29    1 TO  15
    CURRENT LENGTH:   26.69(IN)   16.01(IN)
        CURRENT SCALE:    1.00
        PLOT CELL INDICES:  YES
        PLOT BATHYMETRY:  NO        BATHYMETRY FILE:   N/A
        FTITLE:
 PRESS RETURN TO CONTINUE . . .

AVAILABLE MENU ITEMS:
CHOICE:                     FUNCTION
MENU                        PRINTS THIS LIST OF INSTRUCTIONS
STOP                        ENDS PROCEDURE
FTITLE PLTITL               DECLARES PLOT TITLE...64 CHAR OR LESS
WINDOW IX1, IX2, IY1, IY2   SELECTS PLOT WINDOW
WHOLE                       SELECTS WHOLE GRID FOR PLOTTING
SCALE PLSCAL                SELECTS DESIRED PLOTTING SCALE
INDICES                     CELL INDICES TO BE LABELLED
NOINDICES                   NO LABELLING OF CELL INDICES
BATH BATHFIL                BATHYMETRY VALUES TO BE INDICATED
                            ... BATHYMETRY DATA TO BE READ FROM FILE:
 NOBATH                      BATHYMETRY VALUES WILL NOT BE INDICATED
 SUMMARY                     PRINT CURRENT PLOT FEATURES
 HARDCOPY                    GENERATE THE PLOT (ON THE LOCAL
                             PLOTFILE)
```

```
   CHOOSE AN INSTRUCTION FROM THE MENU:
...MAY BE ABBREV TO FIRST 3 CHAR...
...PLEASE USE UPPERCASE...
```

A selection is made from the available menu items given in Table A-3.

Table A-3

DRAWIT Instructions

Instruction	Data	Description
MENU		Displays instruction commands.
STOP		Terminates program execution.
TITLE	title	Writes a title of up to 64 characters on plot.
WINDOW	IX1,IX2,IY1,IX2 (integers)	Defines a subgrid area to be plotted. IX1 = minimum x-axis cell index IX2 = maximum x-axis cell index IY1 = minimum y-axis cell index IY2 = maximum y-axis cell index
WHOLE		Entire grid will be plotted.
SCALE		Plotting scale to enlarge or shrink grid size on output medium.
INDICES		Cell indices will be printed on plot.
NOINDICES		Cell indices will not be printed on plot.
BATH	file name	Bathymetry values, supplied from file listed in instruction, will be printed on plot.
NOBATH		Bathymetry values will not be printed.
SUMMARY		Displays current plotting parameters.
HARDCOPY		Produces plot.

The user selects not to plot cell indices:

```
    NOI
            PLOT CELL INDICES:  NO


    CHOOSE AN INSTRUCTION FROM THE MENU:
         ...MAY BE ABBREV TO FIRST 3 CHAR...
         ...PLEASE USE UPPERCASE...
```

The user selects the plot generation option:

```
    HAR

      END OF DISSPLA 10.0 -- 1375 VECTORS IN 1 PLOTS.
      RUN ON 10/25/90 USING SERIAL NUMBER 60 AT USA VICKSBURG CORPS OF
      ENGINEERS
      PROPRIETARY SOFTWARE PRODUCT OF ISSCO, SAN DIEGO, CALIF.
      139 VIRTUAL STORAGE REFERENCES; 4 READS; 0 WRITES.


      CHOOSE AN INSTRUCTION FROM THE MENU:
         ...MAY BE ABBREV TO FIRST 3 CHAR...
         ...PLEASE USE UPPERCASE...
```

The user selects to end the DRAWIT procedure:

```
    STO

    *** PROGRAM ENDING:   0 PLOTS GENERATED
     STOP
    CP: 0.080S, Wallclock:  111.689s

    *** END OF CMSPOST PROCEDURE
```

51. To display the grid on a terminal screen, the user sets the terminal to TEK 4014 using the set up key and enters the command:

```
      h2crplc1:larry$ /u3/h2crplc0/cmsplot
```

The system responds:

```
        ENTER POST-PROCESSOR DIRECTIVES

        PLOT FILE GENERATED BY PID18433
                     AT ISSCO
                     ON OCT 25, 1990  14:27
```

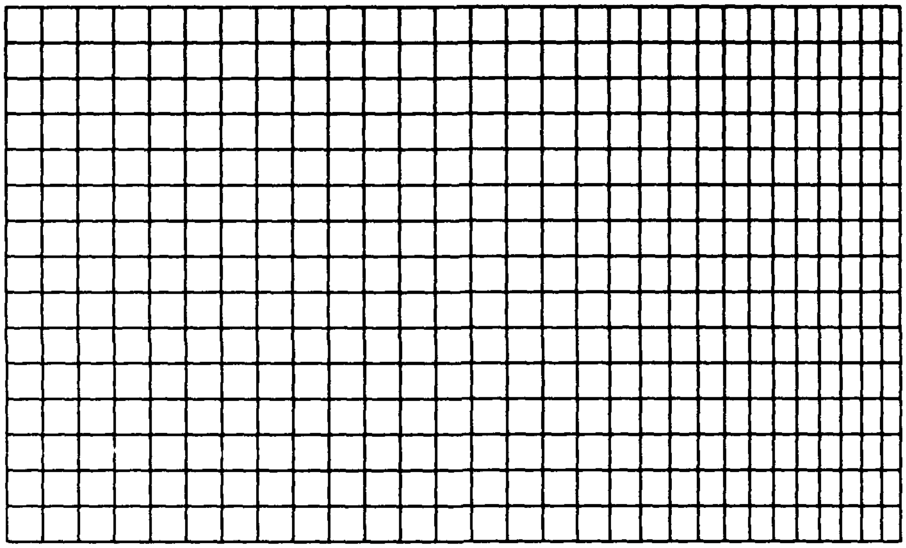


Figure A-4. Sample grid from program DRAWIT

The plotting file can be displayed on the VAX 8800 by following the procedure outlined below. The metafile created by the CRAY Y-MP DRAWIT program (metfil) is converted to a hexafile (metafile.hex) using the CRAY Y-MP system utility meta2hex as follows:

```
h2crplcl:larry$  meta2hex

****************
*  CA-DISSPLA  *
*   META2HEX   *
****************

Enter name of DISSPLA metafile to be converted [popfil]:
metfil

Enter name of output hex metafile [metafile.hex]:  <ret>

* Conversion complete - output file is metafile.hex *
STOP
```

The user then transfers the hexafile to the VAX 8800 as follows:

```
h2crplcl:larry$  ftp wesim3
Connected to wesim3.
220 wesim3.army.mil Wollongong FTP Server  (Version 5.1)  at Wed
Oct 10 10:56T
Name (wesim3:h2crplcl):  h2crplc0
331 Password required for h2crplc0.
Password:  __________
230  User logged in, default directory $DISK2:[H2CRPLC0]
Remote system type is VMS
```

```
ftp> put metafile.hex
200 PORT Command OK.
125 File transfer started correctly
226 File transfer completed ok
119481 bytes sent 1.2 seconds (97Kbytes/s)
ftp> quit
221 Goodbye.
h2crplcl:larry$
Connection closed to larry.wes.army.mil
```

The hexafile is then converted to a metafile on the VAX 8800 using the system utility HEX2META as follows:

```
$ HEX2META

****************
*  CA-DISSPLA  *
*   HEX2META   *
****************

Enter name for output binary DISSPLA metafile [popfil.dat]:  <ret>

Enter name of input DISSPLA hex metafile [metafile.hex]:  <ret>

* Starting translation of DISSPLA hex metafile created on 10/10/90 at
  10:56:40
* CRAY filename was metfil
* Metafile conversion is complete output file is POPFIL.DAT *
```

The output file can then be transferred to the CERC VAX 3300 for plotting on the drum plotter by invoking the command:

```
COPY WESIM3"username password"::$DISK3:[VAX8800 acct]popfil.dat pictur.dat
```

52. To plot on the drum plotter located in the CERC terminal room, the user logs onto the terminal adjacent to the drum plotter by typing:

```
C> G Surf (Inlet, or Aeolus)
```

The system will prompt the user for a VAX 3300 user name and password. Once logged onto the VAX 3300, the user must create a file called DRUMPLT.FOR as given below:

```
CALL HP75
CALL METNAM('PICTUR',6)
CALL DISPOP(1)
STOP
END
```

To compile and link the DRUMPLT file, the user types:

```
$ DISS DRUMPLT
```

To produce an actual size plot, type:

```
$ Run Drumplt
```

Program LISTIT

53. Program LISTIT produces a file containing a listing of the stretched rectilinear coordinates computed from the stretching coefficients generated by program MAPIT. Therefore, program MAPIT must be executed first, and its output file stored as an indirect access file before attempting to use program LISTIT.

Program execution

54. Program LISTIT is executed interactively by the commands:

```
h2crplcl:larry$/u3/h2crplc0/cms
```

The CMS responds:

```
          W E L C O M E   T O . . .

     XXXXX          X     X       XXXXX
    X     X         XX   XX      X     X
    X               X X X X      X
    X               X  X  X       XXXXX
    X               X     X            X
    X     X         X     X      X     X
     XXXXX          X     X       XXXXX

             Return for more...
```

```
*******************************************************************
*                         C M S   COMPONENTS                      *
*-----------------------------------------------------------------*
*  Options:                                                       *
*                                                                 *
*  CMSGRID (Maps, plots, and lists the numerical grid)  ------> 1 *
*                                                                 *
*  CMSMODEL (Compiles, links, loads, and executes                 *
*                 numerical models)  ----------------------> 2    *
*                                                                 *
*  CMSPOST (Plots and lists model outputs)  -----------------> 3  *
*                                                                 *
*  CMSUTIL (Additional "utility" programs)  -----------------> 4  *
*                                                                 *
*  Exit CMS  ---------------------------------------------> e     *
*******************************************************************
```

Enter option number -----------------------> 1

The CMS responds:

```
   CCCC     M     M    SSSS     GGGG    RRRRR    I   DDDDD
  C    C    MM   MM   S    S   G    G   R    R   I   D    D
 C          M M M M   S        G        R    R   I   D     D
 C          M  M  M    SSSS    G        RRRRR    I   D     D
 C          M     M        S   G   GGG  R  R     I   D     D
  C    C    M     M   S    S   G    G   R   R    I   D    D
   CCCC     M     M    SSSS     GGGG    R    R   I   DDDDD


                    Return for more...
```

```
*******************************************************************
*                                                                 *
*                USING THE COASTAL MODELING SYSTEM                *
*                                                                 *
*******************************************************************
*                                                                 *
*  Options:                                                       *
*                                                                 *
*    On-Line Help ------------------------------------------> 1  *
*                                                                 *
*    Enter CMSGRID Module ----------------------------------> 2  *
*                                                                 *
*    Return to Main Menu -----------------------------------> 3  *
*                                                                 *
*******************************************************************
```

Enter option number ------------------> 2

```
************************************************************
*                    CMSGRID COMPONENTS                    *
************************************************************
*   MAPIT: (Stretched/constant rectangular                 *
*          coordinate grid generator) --------------> 1   *
*                                                          *
*   DRAWIT:    (Graphical program to plot grids            *
*              generated by MAPIT) -----------------> 2   *
*                                                          *
*   LISTIT:    (Program to print grid coordinate           *
*              points) ----------------------------> 3    *
*                                                          *
*   EXIT:  (Terminate computer session) ------------> 4   *
************************************************************
```

The user is prompted to select a CMSGRID component:

Enter option number -----------------> 3

The CMS responds:

```
X            X      XXXXX   XXXXXXX     X     XXXXXXX
X            X     X     X     X        X        X
X            X     X           X        X        X
X            X      XXXXX      X        X        X
X            X           X     X        X        X
X            X     X     X     X        X        X
XXXXXXXX     X      XXXXX      X        X        X

                   Return for more...
```

Enter name of the input data set **mock.map**

Enter name of the output file **mock.lst**

The system responds:

```
...NORMAL TERMINATION...PROCESSING FINISHED
  STOP
CP: 0.019S, Wallclock: 0.028s,  10.9% of 6-CPU Machine

*** END OF CMSPOST PROCEDURE
```

Program LISTIT produces an output file containing the grid coordinates. "FACE" indicates the location of the edge of a grid cell and "CENTER" indicates the location of the grid cell center. Output file mock.lst is displayed as follows:

h2crplcl:larry$ [redacted]

*** SUMMARY OF MAPPED REGIONS:

REGION	NO.	CELL FROM	CELL TO	ALPHA FROM	ALPHA TO	A	B	C
XREGION	1	1	30	1.	31.	-1.00000	1.00000	1.00000
YREGION	1	1	15	1.	16.	-1.00000	1.00000	1.00000

*** SUMMARY OF X-COORDINATES:

CELL INDEX	ALPHA	FEATURE	X	X'	X"
-----	1.0	FACE:	0.0000000000	1.0000000000	0.0000000000
1	1.5	CENTER:	0.5000000000	1.0000000000	0.0000000000
-----	2.0	FACE:	1.0000000000	1.0000000000	0.0000000000
2	2.5	CENTER:	1.5000000000	1.0000000000	0.0000000000
-----	3.0	FACE:	2.0000000000	1.0000000000	0.0000000000
3	3.5	CENTER:	2.5000000000	1.0000000000	0.0000000000
-----	4.0	FACE:	3.0000000000	1.0000000000	0.0000000000
4	4.5	CENTER:	3.5000000000	1.0000000000	0.0000000000
-----	5.0	FACE:	4.0000000000	1.0000000000	0.0000000000
5	5.5	CENTER:	4.5000000000	1.0000000000	0.0000000000
-----	6.0	FACE:	5.0000000000	1.0000000000	0.0000000000
6	6.5	CENTER:	5.5000000000	1.0000000000	0.0000000000
-----	7.0	FACE:	6.0000000000	1.0000000000	0.0000000000
7	7.5	CENTER:	6.5000000000	1.0000000000	0.0000000000
-----	8.0	FACE:	7.0000000000	1.0000000000	0.0000000000
8	8.5	CENTER:	7.5000000000	1.0000000000	0.0000000000
-----	9.0	FACE:	8.0000000000	1.0000000000	0.0000000000
9	9.5	CENTER:	8.5000000000	1.0000000000	0.0000000000

REFERENCE

EM 1110-2-1412. 1986. "Engineering and Design Storm Surge Analysis," Department of the Army Corps of Engineers, Office of the Chief of Engineers.

APPENDIX B: CMSUTIL

Introduction

1. CMSUTIL is the software package in the Coastal Model System (CMS) that provides the user access to programs that supplement the CMS models. Presently, the following programs reside in this package:

TIDEGEN	Generates tidal elevation time-history data at select locations from tidal harmonic constituents.
TIDECON	Synthesizes tidal harmonic constituents from a time series of hourly tidal elevations.

2. Descriptions of each program, including data requirements and execution procedures, are provided in the following sections.

Program TIDEGEN

3. Program TIDEGEN generates a time series of tidal elevations from tidal harmonic constituents. The mathematical procedures used to produce the data are described in Schureman*. This program can simultaneously process records for a maximum of 60 gage locations. The following data are required for each gage:

a. Longitude of the gage.

b. Constituents that are applicable to that gage location.

c. Amplitudes and epochs corresponding to each constituent selected in item b.

d. Starting date and local time at the specified longitude.

4. The National Ocean Service (NOS) provides amplitude and epoch data for different tidal constituents at US coastal locations. To facilitate the use of NOS information, program TIDEGEN uses the same constituent names as NOS. Table B-1 presents a list of those constituents available for use in this program.

5. The output of TIDEGEN consists of a file containing the computed water surface elevations and an optional printout of the constituents. Model WIFM contains TIDEGEN as a component to compute the tide data internally during the course of a simulation. However, it is suggested that the user

---

* P. Schureman, 1958, "Manual of Harmonic Analysis and Prediction of Tides," Special Publication No. 98, US Coast and Geodetic Survey, Department of Commerce, Washington, DC.

reproduce the data with TIDEGEN before running WIFM to check the accuracy of the program output. Tide elevations may be plotted using program HYDPLT in package CMSPOST (Appendix C).

6. The first tidal elevation in the output file corresponds to the starting date and time. Time intervals between subsequent tidal elevations are constant; however, the time interval depends on the total length of time for which output data are generated. Table B-2 presents the time intervals at which the output data are generated.

Data requirements

7. An instruction file containing certain input data records must be created before executing the TIDEGEN program (see Table B-3). Each instruction or data record in the file must begin with a record identifier starting in column 1, which identifies the type of data. For example, record identifier EPCH1 is for the epoch of each constituent associated with gage 1, AMPL1 is for the amplitude of each constituent associated with gage 1, and so forth. Table B-3 presents the instruction file records applicable to this program. Data to the right of the record identifiers are read format-free. These data must be separated by at least one blank column (commas cannot be used). Note the "Type" designations [R] and [O] in column 1 of Table B-3 indicate required and optional records, respectively.

8. The TITLE record gives the simulation a general title that can be used by the plotting program, HYDPLT. The TIMES record specifies the starting time for computing tidal elevation data. Parameters contained on this record include the year, month, day, and hour for beginning the simulation and the length of the simulation, in hours. The GNAM_ record is used to give a reference name to a particular time series, or gage. (The _ is explained in the following paragraph.)

9. Each gage requires one set of GNAM_, LONG_, CNST_, AMPL_, and EPCH_ commands, entered in the order specified in Table B-3. The record identifiers describing the gage, constituent, amplitude, epoch, and longitude data require a qualifier or number that corresponds to the gage number. This qualifier must be immediately adjacent to the record identifier. The first gage has the qualifier "1," the second gage has the qualifier "2," and so forth.

10. The LONG_ provides the longitude (in degrees) west of the Greenwich meridian for the specific gage. If the command LONG1 is omitted, the time

Table B-1

List of Available Constituents

Reference Number	NOS Name	Description
1	M2	Semidiurnal
2	S2	Semidiurnal
3	N2	Semidiurnal
4	K1	Diurnal
5	M4	Shallow-water quarter diurnal
6	O1	Diurnal
7	M6	Shallow-water sixth diurnal
8	MK3	Shallow-water terdiurnal
9	S4	Shallow-water quarter diurnal
10	MN4	Shallow-water quarter diurnal
11	NU2	Semidiurnal
12	S6	Shallow-water sixth diurnal
13	MU2	Semidiurnal
14	2N2	Semidiurnal
15	OO1	Diurnal
16	LAMBDA2	Semidiurnal
17	S1	Diurnal
18	M1	Diurnal
19	J1	Diurnal
20	MM	Long-period
21	SSA	Long-period
22	SA	Long-period
23	MSF	Long-period
24	MS	Long-period
25	RHO1	Diurnal
26	Q1	Diurnal
27	T2	Semidiurnal
28	R2	Diurnal
29	2Q1	Diurnal
30	P1	Diurnal
31	2SM2	Shallow-water semidiurnal
32	M3	Terdiurnal
33	L2	Semidiurnal
34	2MK3	Shallow-water terdiurnal
35	K2	Semidiurnal
36	M8	Shallow-water eight diurnal
37	MS4	Shallow-water quarter diurnal

Table B-2

TIDEGEN Output Data Time Intervals

Simulation Length hr			Time Interval min
	<	1.5	0.5
1.5	-	3.0	1.0
3.0	-	7.0	2.0
7.0	-	15.0	5.0
15.0	-	25.0	10.0
25.0	-	45.0	15.0
45.0	-	90.0	30.0
90.0	-		60.0

specified in command TIMES would default to Greenwich time. For each selected constituent for a particular gage, the user must specify a corresponding amplitude using record AMPL_. For example, if GNAM1 has constituents M2 and S2, then record AMPL1 would contain two amplitudes, one corresponding to constituent M2 and the other corresponding to S2. Similarly, the epoch is provided for each constituent selected for a particular gage using record EPCH_.

11. Constituents are designated on the CNST_ record by their reference number, or index (see Table B-1) rather than by their names. However, if all 37 constituents are desired, the user may enter "ALL" instead of listing all of the reference numbers. Also, if some of the reference numbers are consecutive, the user can list the first number, immediately followed by a hyphen, then the last reference number (e.g., 5-9 would include constituents 5 through 9 from Table B-1).

Table B-3

Instruction File Records for Program TIDEGEN

Type	CARDID	Data	Default	Description
[R]	TITLE	title	TITLE1	General plot title. Title size is 64 characters.
[R]	TIMES	YR MNTH DAY SHR RHR	none	Time at beginning of computation. YR = calendar year (e.g., 1981). Integer. MNTH = calendar month (e.g., February = 2). Integer. DAY = calendar date. Integer. SHR = starting hour, local time (e.g. 13.) Real. RHR = record length of computed time-histories, hours (e.g. 720.) Real.
[R]	GNAM_	gage name	none	Gage name, up to 45 characters. Qualifier _ referenced to gage number.
[R]	LONG_	longitude	none	Longitude (in deg) west of the Greenwich meridian.
[R]	CNST_	constituent index	none	Constituent index value. Up to 37 constituents can be selected for processing. Qualifier _ referenced to gage number.
[R]	AMPL_	constituent amplitude	none	Amplitude(s) for constituents in command CNST_. (Ft) Command must include one amplitude for each constituent, and amplitudes must be entered in identical order to their respective constituent. Qualifier _ referenced to gage number.
[R]	EPCH_	constituent epoch		Epoch(s) for constituents in command CNST_. (Deg.) Command must include one epoch for each constituent, and epochs must be entered in identical order to their respective constituent. Qualifier _ referenced to gage number.
[O]	GLIST	none	N/A	Prints summary of tidal constituent data.
[O]	DEBUG	none	N/A	Generates output to locate errors in processing.

12. The following example illustrates the structure of the instruction file:

```
TITLE          EXAMPLE INSTRUCTION FILE
TIMES          1987  2  14  12  36
GAGE1          GAGE NO. 1
LONG1          135.0
CNST1          1  3
AMPL1          2.0  0.5
EPCH1      35.0   90.0
GAGE2          GAGE NO. 2
LONG2      135.2
CNST2      3-5
AMPL2      0.25  0.10  0.05
EPCH2     15.0  5.0  45.0
```

13. For this example, two tidal elevation time-histories will be generated. The starting date and time for each gage is 12 noon on 14 February 1987 (local time), and data will be produced, at 10-min intervals, for the 36-hr record length.

14. Gage no. 1 is located 135.0 deg west of the Greenwich meridian (i.e., command LONG1). Constituents M2 and N2, selected with command CNST1 (see Table B-1) are used to generate the tidal elevation time-history. Constituent M2 has an amplitude of 2.0 ft and an epoch of 35.0 deg. Constituent N2 has an amplitude and epoch of 0.5 ft and 90.0 deg, respectively.

15. Three constituents are used to generate the tidal elevation time-history for the second gage. These constituents are N2, K1, and M4. Amplitudes and epochs are assigned to their respective constituents in the same fashion as for gage no. 1.

<u>Program execution</u>

16. After creating and saving the instruction file, the user enters the following interactive command at the system prompt:

```
h2crplc1:larry$/u3/h2crplc0/cms
system prompt     user entry
```

It should be noted that user entries are shown as shaded, and CMS response "screens" are shaded boxes.

The CMS responds:

```
W E L C O M E   T O . . .

  XXXXX         X     X         XXXXX
 X     X        XX   XX        X     X
 X              X X X X        X
 X              X  X  X         XXXXX
 X              X     X              X
 X     X        X     X        X     X
  XXXXX         X     X         XXXXX

         Return for more...
```

```
**********************************************************************
*                         C M S   COMPONENTS                         *
*--------------------------------------------------------------------*
*  Options:                                                          *
*                                                                    *
*  CMSGRID (Maps, plots, and lists the numerical grid)  ------> 1   *
*                                                                    *
*  CMSMODEL (Compiles, links, loads, and executes                    *
*                 numerical models) ------------------------> 2     *
*                                                                    *
*  CMSPOST (Plots and lists model outputs)  -----------------> 3     *
*                                                                    *
*  CMSUTIL (Additional "utility" programs)  -----------------> 4     *
*                                                                    *
*  Exit CMS  ------------------------------------------------> e     *
**********************************************************************
```

To enter CMSUTIL, the user enters a value of 4:

```
Enter option number  ------------------------> 4
```

The CMS responds:

```
  CCCC       M     M     SSSS     U    U    TTTTTTT    I    L
 C    C      MM   MM    S    S    U    U       T       I    L
C            M M M M    S         U    U       T       I    L
C            M  M  M     SSSS     U    U       T       I    L
C            M     M         S    U    U       T       I    L
 C    C      M     M    S    S    U    U       T       I    L
  CCCC       M     M     SSSS      UUUU        T       I    LLLLLL

                         Return for more...
```

```
*******************************************************************
*                                                                 *
*                 USING THE COASTAL MODELING SYSTEM               *
*                                                                 *
*******************************************************************
*                                                                 *
*  Options:                                                       *
*                                                                 *
*    On-Line Help ------------------------------------------> 1   *
*                                                                 *
*    Enter CMSUTIL Module ----------------------------------> 2   *
*                                                                 *
*    Return to Main Menu -----------------------------------> 3   *
*                                                                 *
*******************************************************************
```

```
Enter option number --------------> 2
```

```
*******************************************************************
*                       C M S U T I L   M E N U                   *
*******************************************************************
*                                                                 *
*   TIDEGEN  Generates a time series of tidal elevations          *
*            from harmonic and tidal constituents. -----> 1       *
*                                                                 *
*   TIDECON  Synthesizes harmonic constituents from time          *
*            series of hourly tidal elevation data. ----> 2       *
*                                                                 *
*   EXIT -------------------------------------------------> 3     *
*                                                                 *
*******************************************************************
```

To execute program TIDEGEN, the user enters a value of 1:

Enter option number ----------------------> 1

The CMS responds:

```
TTTTTTT    I    DDDDD     EEEEEE     GGGG      EEEEEE    N     N
   T       I    D    D    E         G    G     E         NN    N
   T       I    D     D   E        G           E         N N   N
   T       I    D     D   EEEE     G           EEEE      N  N  N
   T       I    D     D   E        G   GGG     E         N   N N
   T       I    D    D    E         G    G     E         N    NN
   T       I    DDDDD     EEEEEE     GGGG      EEEEEE    N     N

                       Return for more...
```

Enter the name ofthe instruction file: tidegen.ins

The user can choose any meaningful naming convention when selecting filenames. For example, the user may choose a project name with different extensions for each file.

Enter the name of the output file containing water surface elevations:

tidegen.hyd

Constituent print-out desired? y

Enter the name of the constituent output file: tidegen.con

The CMS submits a batch job to the CRAY Y-MP and the system responds:

Request 1234.larry submitted to queue prime.

The user enters a 3 to terminate the CMSUTIL session and return to the main menu.

Program output

17. Program TIDEGEN's output file containing the time series of tidal elevations for each gage can be printed for inspection of the values, or it can be used as direct input to models WIFM and CLHYD or the plotting program HYDPLT in package CMSPOST.

```
*******************************************************************
*                    C M S U T I L   M E N U                      *
*******************************************************************
*                                                                 *
*   TIDEGEN  Generates a time series of tidal elevations          *
*            from harmonic and tidal constituents. -----> 1       *
*                                                                 *
*   TIDECON  Synthesizes harmonic constituents from time          *
*            series of hourly tidal elevation data. ----> 2       *
*                                                                 *
*   EXIT  -----------------------------------------------> 3      *
*                                                                 *
*******************************************************************
```

Program TIDECON

18. Program TIDECON synthesizes harmonic constituents from a time series of hourly tidal elevation data. This program requires the following data:

- a. Time series of tidal elevation data in the format used by the National Ocean Service (NOS) (see Table B-4).
- b. Longitude of the gage.
- c. Constituent(s) that are desired.
- d. Starting date of the tide data. Starting time of data must be at midnight (HR 0).

19. Tide data must be free of gaps, spikes, and other errors in order to compute accurate constituents. No error correction or data reconstruction features exist in this program. Furthermore, the tidal elevation time-history data set length required varies from constituent to constituent. A minimum of 30 days of continuous hourly data are needed to resolve lunar constituents (for example, M2). However, some longer period constituents (which usually have a relatively small effect on the total tidal elevation) may require as many as 19 years of continuous hourly data to obtain accurate results. Hence, the user should plot the time-history data generated using the computed constituents to check the accuracy of program TIDECON output. (See program HYDPLT in package CMSPOST (Appendix C) to plot time-history data.)

20. Output consists of four files containing: (1) original gage data, (2) constituent data, (3) synthesized gage data, and (4) residual difference between original and synthesized gage data. Items (1), (3), and (4) are

produced to check the accuracy of the constituents generated by this program. These files may be plotted using program HYDPLT in package CMSPOST.

Data requirements

21. An instruction file must be created before execution. This file must contain the following information:

a. Tide gage file name.

b. Date of the first elevation record in the data file.

c. Constituents to be generated.

d. Gage longitude.

22. This information is listed in the form of data records where each record must start with an identifier, in column 1. Table B-5 presents the allowable records, with an explanation of each, required by this program. Furthermore, the commands must be entered into the instruction file in the order shown in Table B-5. Required records are indicated by "Type [R]" and must be contained in the instruction file. Such records include: FILES, TIME, CNST, and LONG. Optional records are indicated by "Type [O]" and are optionally included in the instruction file. Such records include the TITLE and DEBUG records.

23. Data to the right of the record identifier are read format-free. These data must be separated by at least one blank column (commas cannot be used). The FILES record contains the name of the file containing gage data. The TIMES record specifies the start time for the elevation data contained in the file specified on the FILES record. The parameters included on this record are the year, month, and day at the start of the elevation data set.

24. Constituents selected for processing are specified with record CNST. Constituents are designated on the CNST command by their reference number (see Table B-1) rather than by their names. However, if all 37 constituents are desired, the user may enter "ALL" instead of listing all of the reference numbers. Also, if some of the reference numbers are consecutive, the user can list the first number, immediately followed by a hyphen, then the last reference number (e.g., 5-9 would generate constituents 5 through 9 on Table B-1). Record LONG specifies the west longitude of the gage, in degrees relative to the Greenwich meridian. The user may optionally select a title (record TITLE) to be used for plotting results. Record DEBUG can be included to perform error processing.

Table B-4

NOS Tidal Elevation Record Format

Record Columns	Data Type	Data Field Description
1 - 19	Character	Tide Station Name or seven-digit station ID number.
20 - 25	Integer	Date (YYMMDD).
26	Integer	Card number, either 1 or 2, of 2 per day. Card number 1 corresponds to tidal elevation data starting at hour 0.
27 - 31	Integer	Gage longitude in decimal degrees times 100 (e.g. 124.18 deg = 12418)
32	Character	Longitude direction from Greenwich, England (E or W).
33 - 36	Integer	Tidal elevation at hour 0 or 12.
37 - 40	Integer	Tidal elevation at hour 1 or 13.
41 - 44	Integer	Tidal elevation at hour 2 or 14.
45 - 48	Integer	Tidal elevation at hour 3 or 15.
49 - 52	Integer	Tidal elevation at hour 4 or 16.
53 - 56	Integer	Tidal elevation at hour 5 or 17.
57 - 60	Integer	Tidal elevation at hour 6 or 18.
63 - 64	Integer	Tidal elevation at hour 7 or 19.
65 - 68	Integer	Tidal elevation at hour 8 or 20.
69 - 72	Integer	Tidal elevation at hour 9 or 21.
73 - 76	Integer	Tidal elevation at hour 10 or 22.
77 - 80	Integer	Tidal elevation at hour 11 or 23.

Table B-5

Instruction File Commands for Program TIDECON

Type	CARDID	Data	Default	Description
[R]	FILES	file name	none	Name of file to be containing gage data in NOS format. Must be first record listed in instruction file.
[R]	TIMES	YR MNTH DAY	none	Time at beginning of computation. YR = calendar year (e.g., 1981). Integer. MNTH = calendar month (e.g., February =2). Integer. DAY = calendar date. Integer.
[R]	CNST	constituent index	none	Constituent index value. Up to 37 constituents can be selected for processing.
[R]	LONG	GLONG	none	West longitude of gage, in degrees. Omit record if time on command TIMES is Greenwich time.
[O]	TITLE	title	TITLE1	General plot title. Title size is 64 characters.
[O]	DEBUG	none	N/A	Generates output to locate errors in processing.

B-14

25. Time series input data must be in the format used by the NOS Tidal Evaluation Group (Table B-4). The following requirements must also be met:

- a. The first tide record must begin at midnight (HR 0) of the date specified in the instruction file. If the user's data begin at a time other than midnight, then the time series should be truncated to begin at midnight of the following day.
- b. Each record must contain 12 hourly values, with the first record starting at hour 0, the second record starting at hour 13, the third record starting at hour 0 of the second day, etc.
- c. Tidal heights are entered as integers and measured in hundredths of a foot. (For example, the value "1247" translates to 12.47 ft.)

26. This program processes only the elevation data listed in columns 33 through 80 of the time series data file. Columns 1 through 32 are for optional documenting of the data set, and data in these columns are not used by the program.

27. The following example illustrates the structure of an instruction file:

```
FILES     MYDAT
TIMES     1987  2  15
LONG      135.0
CNST      1  3  6-8
TITLE     EXAMPLE INSTRUCTION FILE
```

28. In this example, tidal elevation time-history data have a starting date of 15 February 1987. The starting time, specified in the NOS data set, must be at midnight (0 hr). The time-history data will be analyzed to derive the amplitudes and epochs for the five constituents listed in command CNST. These constituents are M2, N2, O1, M6, and MK3 (see Table B-1).

Program execution

29. After creating and saving the instruction file, enter the following interactive commands to execute the program:

```
h2crplc1:larry$/u3/h2crplc0/cms
```

The CMS responds:

```
              W E L C O M E   T O . . .

   XXXXX          X     X        XXXXX
  X     X         XX   XX       X     X
  X               X X X X       X
  X               X  X  X        XXXXX
  X               X     X             X
  X     X         X     X       X     X
   XXXXX          X     X        XXXXX

                  Return for more...
```

```
**********************************************************************
*                           C M S   COMPONENTS                        *
*---------------------------------------------------------------------*
*  Options:                                                           *
*                                                                     *
*  CMSGRID (Maps, plots, and lists the numerical grid)  ------>  1    *
*                                                                     *
*  CMSMODEL (Compiles, links, loads, and executes                     *
*                numerical models)  ----------------------->  2    *
*                                                                     *
*  CMSPOST (Plots and lists model outputs)  ----------------->  3    *
*                                                                     *
*  CMSUTIL (Additional "utility" programs)  ----------------->  4    *
*                                                                     *
*  Exit CMS  ---------------------------------------------------->  e    *
**********************************************************************
```

To enter CMSUTIL, the user enters a value of 4:

```
Enter option number  ----------------------->  4
```

The CMS responds:

```
  CCCC       M     M     SSSS     U     U    TTTTTTT     I     L
 C    C      MM   MM    S    S    U     U       T        I     L
C            M M M M    S         U     U       T        I     L
C            M  M  M     SSSS     U     U       T        I     L
C            M     M         S    U     U       T        I     L
 C    C      M     M    S    S    U     U       T        I     L
  CCCC       M     M     SSSS      UUUU         T        I     LLLLLL

                        Return for more...
```

```
**********************************************************************
*                                                                    *
*                 USING THE COASTAL MODELING SYSTEM                  *
*                                                                    *
**********************************************************************
*                                                                    *
*  Options:                                                          *
*                                                                    *
*    On-Line Help  -------------------------------------------> 1    *
*                                                                    *
*    Enter CMSUTIL Module  -----------------------------------> 2    *
*                                                                    *
*    Return to Main Menu  ------------------------------------> 3    *
*                                                                    *
**********************************************************************
```

```
Enter option number  -------------->  2
```

```
********************************************************************
*                      C M S U T I L   M E N U                     *
********************************************************************
*                                                                  *
*   TIDEGEN  Generates a time series of tidal elevations           *
*            from harmonic and tidal constituents.  ---->  1       *
*                                                                  *
*   TIDECON  Synthesizes harmonic constituents from time           *
*            series of hourly tidal elevation data. ---->  2       *
*                                                                  *
*   EXIT  ------------------------------------------------>  3     *
*                                                                  *
********************************************************************
```

To execute program TIDECON, the user enters a value of 2:

Enter option number --------------------> 2

The CMS responds:

```
TTTTTTT     I    DDDDD       EEEEEE     CCCC        OO        N     N
   T        I    D    D      E         C    C      O  O       NN    N
   T        I    D     D     E        C           O    O      N N   N
   T        I    D     D     EEEE     C           O    O      N  N  N
   T        I    D     D     E        C           O    O      N   N N
   T        I    D    D      E         C    C      O  O       N    NN
   T        I    DDDDD       EEEEEE     CCCC        OO        N     N

                        Return for more...
```

Enter the name of the instruction file tidecon.ins

Again, the user can choose any meaningful naming convention when selecting filenames.

Enter the name of the input file containing time series data tidecon.inp

Enter the name of the time-history and constituent output file tidecon.out

The CMS submits a batch job to the CRAY Y-MP and the system responds:

Request 5678.larry submitted to queue prime.

The user enters 3 to terminate the CMSUTIL session and return to the main menu.

Program output

30. Program TIDECON's output file may be printed for inspection of values. Output files containing time-histories of tide elevations can be used as direct input to the plotting program HYDPLT in package CMSPOST. The actual tidal constituents are output in the same file.

```
*********************************************************************
*                    C M S U T I L   M E N U                        *
*********************************************************************
*                                                                   *
*   TIDEGEN  Generates a time series of tidal elevations            *
*            from harmonic and shallow water tidal                  *
*            constituents.  ---------------------------> 1          *
*                                                                   *
*   TIDECON  Synthesizes harmonic constituents from time            *
*            series of hourly tidal elevation data. ----> 2         *
*                                                                   *
*   EXIT  ----------------------------------------------> 3         *
*                                                                   *
*********************************************************************
```

APPENDIX C: CMSPOST

Introduction

1. CMSPOST is the post-processing package in the Coastal Modeling System (CMS) for displaying output generated by models. CMSPOST's graphical and tabular output will help the user in analyzing model results. Model output is directly read into this package; however, in most cases an instruction file containing information to generate the plots must be created by the user. CMSPOST can also process data not generated by the models; but data must be in the format required by the programs. The types of graphics that can be produced are:

- a. Time-histories of water surface elevations, water and wind velocities, and pressure at discrete locations.
- b. Vector maps, or "snapshots," of water or wind velocities at a specified time in the simulation.
- c. Profile plots showing the spatial distribution of a variable.
- d. Wave ray plots for displaying RCPWAVE output only.

In addition, model SHALWV has its own graphics option (see Chapter 7).

2. All programs are written in FORTRAN 77, and graphics are produced using DISSPLA™ software. Graphic output structure requires use of Tektronix 4014 or compatible terminals.

3. The programs contained in CMSPOST are described in Table C-1. Refer to records RECGAGE, RECSNAPS, PLOTREC, XRECRANG, and YRECRANG in the model documentation for creating and saving data used in CMSPOST.

Data Requirements

Instruction file for time-history programs

4. The instruction file contains commands describing how the data set(s) are to be processed. Each line in the file must begin with a record identifier that signifies an operation. The record identifier must begin in column 1 of the line; the program will not right-justify these variables. The data entered after the record identifier, unless otherwise noted, are read free format and must be separated by at least one blank column (commas can not be used). All instruction file commands for the time-history programs are listed in Table C-2.

Table C-1

Post-Processing Programs

Program	Description	Applicable to
HYDPLT	Produces time-series plots of water surface fluctuations, wind and water velocities, pressure head and discharge.	SPH, WIFM, CLHYD
HYDLST	Prints time-series of water surface fluctuations water velocities, wind velocities, and angles, pressure head, and water discharge.	SPH, WIFM, CLHYD
HYDADD	Concatenates time-history records from successive runs of a model for processing by HYDLST or HYDPLT.	SPH, WIFM, CLHYD
SNAPVEC	Produces vector plots of water and wind velocity fields.	SPH, WIFM, CLHYD
SNAPLST	Prints field arrays described in SNAPVEC. Vectors may be printed as either x-y components or as magnitude and direction.	SPH, WIFM, CLHYD
PROFPLT	Profile plot of specified field variable.	SPH, WIFM, CLHYD, RCPWAVE
RAYPLT	Wave ray plots from model RCPWAVE.	RCPWAVE

5. Programs that create time-history plots and tables can process a maximum of four separate data sets simultaneously. Furthermore, data from one file can be plotted with data from another on the same graph.

6. All commands, categorized as format [F] or select [S] commands, may appear in any order. Format commands refer to operations that modify the default parameters controlling the format of the plots or tables. For example, the type of modifications that can be made include changing axes titles, or the minimum, maximum, and increment values used to plot the independent variable.

7. Select commands are used to select the data set, type of data, and the time-history to be plotted or tabularized. The first letter in the record identifier for select commands represents the type of data (e.g., T = water surface level data) that is to be processed. Immediately adjacent to the record identifier is a qualifier that identifies which file is to be used.

Table C-2

Instruction File Commands for Time-History Plots

Type	CARDID	Data	Default	Description
[F]	DEBUG	none	N/A	Generates output to locate errors in processing.
[F]	REPRT	none		Produces plots in report format.
[F]	PFORM	N	4	Number of graphs plotted per page. Maximum of 4.
[F]	TITLE	title	TITLE1	General plot title. Title size is 64 characters.
[F]	TIMES	TMIN TMAX TINC		Specify time plotting limits and increment. Default values are calculated from the data set.
[F]	TAXIS	EMIN EMAX EINC	-10. 10. 2.	Elevation axis plotting limits and increment.
[F]	VAXIS	VELMAX VELINC	10. 1.	Velocity axis plotting limit and increment.
[F]	WAXIS	WMAX WINC PMAX PINC	120. 20. 5. 1.	Wind and pressure plotting limits. Pressure is ignored if not saved.
[F]	RAXIS	RMAX RINC RNORM	10. 1. 5.	Range discharge plotting limits and normalization factor.
[F]	TTITL	title	ELEVATION (unit)	Elevation axis title. Title size is 17 characters.
[F]	WTITL	title	WIND MAGNITUDE (unit)	Wind velocity axis title. Title size is 20 characters. Units supplied from gage file.
[F]	PTITL	title	PRESSURE HEAD (unit)	Pressure head axis title. Title size is 19 characters. Units supplied from gage file.

(Continued)

(Sheet 1 of 3)

Table C-2 (Continued)

Type	CARDID	Data	Default	Description
[F]	RTITL	title	FLOW (unit)	Range discharge axis title. Title size is 18 characters. Units supplied from gage file.
[F]	PENUP	X	none	Value that will interrupt plotting when encountered in data set. Used to replace missing or bad data when no lines through bad data are wanted.
[F]	XAXIS	title	TIME (unit)	Time axis title. Title size is 17 characters. Units supplied from gage file.
[F]	NHCPY	none		Overrides program code to produce hard copies of plots.
[S]	TGAG_	gage numbers	none	Select command to process elevations. Qualifier _ referenced to gage file number.
[S]	WGAG_	gage numbers	none	Select command to process wind velocities and pressures. Qualifier _ referenced to gage file number.
[S]	VGAG_	gage numbers	none	Select command to process water velocities. Qualifier _ referenced to gage file number.
[S]	TADJ_	adjustment values	0.0	Values added to water surface elevations. Procedure applied to gages selected according to position in matrix. Qualifier _ referenced to gage file number.

(Continued)

(Sheet 2 of 3)

Table C-2 (Concluded)

Type	CARDID	Data	Default	Description
[S]	TSPL_	index increment	1	Integers for specifying the plotting/printing frequency of elevation gage points. A value of 1 for every point to be plotted, 2 for every second point in array, etc. Procedure applied to gages selected by position in matrix. Qualifier _ referenced to gage file number.
[S]	VSPL_	index increment	1	Integers for specifying the plotting/printing frequency of water velocity gage points. A value of 1 for every point to be plotted, 2 for every second point in array, etc. Procedure applied to gages selected by position in matrix. Qualifier _ referenced to gage file number.
[S]	WSPL_	index increment	1	Integers for specifying the plotting/printing frequency of wind velocity gage points. A value of 1 for every point to be plotted, 2 for every second point in array, etc. Procedure applied to gages selected by position in matrix. Qualifier _ referenced to gage file number.
[S]	RSPL_	index increment	1	Integers for specifying the plotting/printing frequency of range gage points. A value of 1 for every point to be plotted, 2 for every second point in array, etc. Procedure applied to gages selected by position in matrix. Qualifier _ referenced to gage file number.

(Sheet 3 of 3)

This qualifier is either the number corresponding to the order in which the file names are entered, or the character string "ALL." If the string "ALL" is used, then all processing procedures selected with this command will be performed on all files.

8. Gage numbers are listed after the record identifier for those gages that the user wishes to process. If the gages are consecutive in value, the user can list the first and last gage numbers, separated by a hyphen.

9. When processing more than one file simultaneously, the select commands form a "plotting matrix" that determines the contents of each plot. One plot will be produced for each column in the matrix. The number of non-zero entries in each column of the matrix determine the number of lines drawn on each plot. The nonzero entries are the gage numbers whose time-histories are to be plotted. The command qualifiers, which define the matrix rows, designate the file containing the gage data. The following example illustrates this matrix structure for files AFILE, BFILE, CFILE, and DFILE:

TGAG1	3	0	1-5
TGAG2	0	4	1-5
TGAG3	0	2	1-5
TGAG4	0	0	1-5
	Plot 1	Plot 2	Plots 3-7

10. A total of seven water surface elevation plots (or tables) will be generated from the four files. Command qualifier 1 (in command TGAG1) corresponds to file AFILE, qualifier 2 corresponds to BFILE, etc. The first plot will contain the time-history of gage 3 stored in file AFILE. (Zeros must be entered for null gages.) The second plot will contain two time-histories, one of gage 4 in file BFILE and the other gage 2 in CFILE. The third column will produce five plots. The third plot will contain the time-histories of gage 1 from each of the four files. The fourth plot will contain time-histories of gage 2, also from all four files, and so forth, with the seventh plot being time-histories of gage 5 from all four files.

Instruction file for snapshot programs

11. Instruction file requirements for the snapshot programs are similar to those required by the time-history programs:

a. Each command in the file must begin with a record identifier starting in column 1.

b. Format and select commands may appear in any order.

c. Data entered after the record identifier are read free-format.

12. In contrast to the time-history programs, the snapshot programs can process only one file at a time. All snapshot instruction file commands are described in Table C-3. Those applicable to each program are listed in the program descriptions.

Table C-3

Instruction File Commands for Snapshot Plots

Type	CARDID	Data	Default	Description
[F]	DEBUG	none		Generates output to locate errors in processing.
[F]	GAGLOC	none		Plots numerical gage locations on snapshots.
[F]	TITLE	title	TITLE1	General plot title. Title size is 64 characters.
[F]	TIMES	TIME	ALL	Time(s),in TUNITS, of snapshot(s) to be plotted. TIME = "ALL" results in all snapshots to be plotted. TIME = "LAST" results in the last snapshot to be plotted.
[S]	VPOLAR_		none	*Water velocities printed as magnitude and* direction.
[S]	WPOLAR_		none	Wind velocities printed as magnitude and direction.
[S]	TFORMT_	format	(15F8.2)	Print format for elevations. Qualifier _ referenced to order of snapshot specified in TIMES.
[S]	VFORMT_	format	(15F8.2)	Print format for water velocities. Qualifier _ referenced to order of snapshot specified in TIMES.
[S]	WFORMT_	format	(15F8.2)	Print format for wind velocities. Qualifier _ referenced to order of snapshot specified in TIMES.

(Continued)

(Sheet 1 of 4)

Table C-3 (Continued)

Type	CARDID	Data	Default	Description
[S]	PFORMT_	format	(15F8.2)	Print format for atmospheric pressures. Qualifier _ referenced to order of snapshot specified in TIMES.
[S]	TSAMPL_	ISMPL JSMPL	1 1	Cell index printing interval for elevations. ISMPL = Print every "ISMPL" cell x-direction JSMPL = Print every "JSMPL" cell y-direction Qualifier _ referenced to order of snapshot specified in TIMES.
[S]	VSAMPL_	ISMPL JSMPL	1 1	Cell index printing interval for water velocities. ISMPL = Print every "ISMPL" cell in x-direction JSMPL = Print every "JSMPL" cell in y-direction *Qualifier _ referenced to order of snapshot* specified in TIMES.
[S]	WSAMPL_	ISMPL JSMPL	1 1	Cell index printing interval for wind velocities. ISMPL = Print every "ISMPL" cell in x-direction JSMPL = Print every "JSMPL" cell in y-direction Qualifier _ referenced to order of snapshot specified in TIMES.
[S]	PSAMPL_	ISMPL JSMPL	1 1	Cell index printing interval for pressures. ISMPL = Print every "ISMPL" cell in x-direction JSMPL = Print every "JSMPL" cell in y-direction Qualifier _ referenced to order of snapshot specified in TIMES.

(Continued)

(Sheet 2 of 4)

Table C-3 (Continued)

Type	CARDID	Data	Default	Description
[S]	TWINDO_	I1 I2 J1 J2	none	Select command to process elevation snapshots. I1 = minimum x-direction cell index to plot I2 = maximum x-direction cell index to plot J1 = minimum y-direction cell index to plot J2 = maximum y-direction cell index to plot Qualifier _ referenced to order of snapshot specified in TIMES.
[S]	VWINDO_	I1 I2 J1 J2	none	Select command to process water velocity snapshots. I1 = minimum x-direction cell index to plot I2 = maximum x-direction cell index to plot J1 = minimum y-direction cell index to plot J2 = maximum y-direction cell index to plot Qualifier _ referenced to order of snapshot specified in TIMES.
[S]	WWINDO_	I1 I2 J1 J2	none	Select command to process wind velocity snapshots. I1 = minimum x-direction cell index to plot I2 = maximum x-direction cell index to plot J1 = minimum y-direction cell index to plot J2 = maximum y-direction cell index to plot Qualifier _ referenced to order of snapshot specified in TIMES.

(Continued)

(Sheet 3 of 4)

Table C-3 (Concluded)

Type	CARDID	Data	Default	Description
[S]	PWINDO_	I1 I2 J1 J2	none	Select command to process atmospheric pressure snapshots. I1 = minimum x-direction cell index to plot I2 = maximum x-direction cell index to plot J1 = minimum y-direction cell index to plot J2 = maximum y-direction cell index to plot Qualifier _ referenced to order of snapshot specified in TIMES.
[S]	VSCALE_	SFAC THRS	10.0 0.05	Select command to specify water velocity vector length. SFAC = vector scale factor (velocity units per inch) THRS = minimum velocity value to plot (velocity units per inch) Qualifier _ referenced to order of snapshot specified in TIMES.
[S]	WSCALE_	SFAC THRS	10.0 0.05	Select command to specify wind velocity vector length. SFAC = vector scale factor (velocity units per inch) THRS = minimum velocity value to plot (velocity units per inch) Qualifier _ referenced to order of snapshot specified in TIMES.

(Sheet 4 of 4)

Program HYDPLT

13. Program HYDPLT is a general purpose program for plotting time-history records generated and stored by the models contained in CMS. The CMS models save the following information for each gage specified by a RECGAGE record: water surface fluctuation, x and/or y water velocity components, and x and y wind velocity components. Atmospheric pressures are saved if SPH is used to generate the wind fields. Discharges, saved using a XRECRANG or YRECRANG record when running the models, are also stored in this file.

14. A maximum of four time-series data files, where each data file can contain up to 120 gages, may be processed simultaneously. No gage can contain more than 1,000 sampling points.

15. An instruction file must be created and stored before execution can begin. Options to change the default plotting formats are included in this file. The following instruction commands, which were described in Table C-2 are valid for this program:

DEBUG	TGAG_	VGAG_	WGAG_	RGAG_
REPRT	TSPL_	VSPL_	WSPL_	RSPL_
PFORM	TAXIS	VAXIS	WAXIS	RAXIS
TITLE	TTITL	VTITL	WTITL	RTITL
TIMES	TADJ_			
PENUP				
XAXIS				
NHCPY				

A sample instruction file for program HYDPLT is given below:

```
PFORM 4
TITLE CLHYD SIMULATION NO 1.  TIDE WITHOUT    FEATHERING
TAXIS -5. 5. 2.5
TGAG1 1-2
DEBUG
```

This file is used in the following example.

To invoke program HYDPLT, the user enters the command:

h2crplcl:larry$ /u3/h2crplc0/cms

(It should be noted that user entries are shown as shaded, and CMS response "screens" are shaded boxes.) The CMS responds:

```
             W E L C O M E   T O . . .

      XXXXX         X     X          XXXXX
     X     X        XX   XX         X     X
     X              X X X X         X
     X              X  X  X          XXXXX
     X              X     X               X
     X     X        X     X         X     X
      XXXXX         X     X          XXXXX

                  Return for more...
```

```
**********************************************************************
*                          C M S   COMPONENTS                        *
*--------------------------------------------------------------------*
*  Options:                                                          *
*                                                                    *
*  CMSGRID (Maps, plots, and lists the numerical grid)  -------> 1   *
*                                                                    *
*  CMSMODEL (Compiles, links, loads, and executes                    *
*                   numerical models)  -------------------------> 2  *
*                                                                    *
*  CMSPOST (Plots and lists model outputs)  ------------------> 3    *
*                                                                    *
*  CMSUTIL (Additional "utility" programs)  ------------------> 4    *
*                                                                    *
*  Exit CMS  -------------------------------------------------> e    *
**********************************************************************
```

To use the CMSPOST programs, the user responds to the CMS prompt with a value of 3:

Enter option number -------------------------> 3

The CMS responds:

```
 CCCC     M     M      SSSS     PPPPP      OO       SSSS   TTTTTTT
C    C    MM   MM     S    S    P    P    O  O     S    S     T
C         M M M M     S         P    P   O    O    S          T
C         M  M  M      SSSS     PPPPP    O    O     SSSS      T
C         M     M          S    P        O    O         S     T
C    C    M     M     S    S    P         O  O     S    S     T
 CCCC     M     M      SSSS     P          OO       SSSS      T


                          Return for more...
```

```
*********************************************************************
*                                                                   *
*                USING THE COASTAL MODELING SYSTEM                  *
*                                                                   *
*********************************************************************
*                                                                   *
*  Options:                                                         *
*                                                                   *
*    On-Line Help ------------------------------------------->  1   *
*                                                                   *
*    Enter CMSPOST Module ----------------------------------->  2   *
*                                                                   *
*    Return to Main Menu ------------------------------------>  3   *
*                                                                   *
*********************************************************************
```

```
Enter option number  --------------->  2
The CMS responds:
```

```
                        CMSPOST

   HYDPLT:  Generates plots of time series output
   HYDLST:  Generates lists of time series output
   HYDADD:  Concatenates two successive time series
  SNAPVEC:  Generates vector plots of model output
  SNAPLST:  Generates lists of field arrays described
            in SNAPVEC
   RAYPLT:  Generates wave ray plots of RCPWAVE output
  PROFPLT:  Generate profile plots of model output
     EXIT:  Terminates this CMSPOST session
```

The user enters: **hydplt**

The CMS responds:

```
H     H    Y     Y   DDDDD     PPPPP    L         TTTTTTT
H     H     Y   Y    D    D    P    P   L            T
H     H      Y Y     D     D   P    P   L            T
HHHHHH        Y      D     D   PPPPP    L            T
H     H       Y      D     D   P        L            T
H     H       Y      D    D    P        L            T
H     H       Y      DDDDD     P        LLLLLLL      T


                    Return for more. . .
```

Enter the name of the instruction file: **hydplt.ins**

Valid user responses are:

TEK40 or tek40 - (hydrograph file will be plotted on TEKTRONIX 4014 or VT240 terminal)

LASER or laser - (hydrograph file plotted on laser printer)

Enter device name **TEK40**

How many input data files will be processed? **5**
***the number of files must be between 1 and 4

```
Do you want to reenter the number of files to be processed?
Enter yes or no to continue  yes

Enter the number of files to be processed  1

Enter the name of the first data set:  hydplt.1

Enter the name of the output file:  hydplt.out
```

The user can choose any meaningful naming convention when selecting filenames. For example, the user may choose a project name with different extensions for each simulation.

The CMS submits a batch job to the CRAY Y-MP and the system responds:

```
Request 4359.larry submitted to queue:prime
```

CMSPOST

HYDPLT:	Generates plots of time series output
HYDLST:	Generates lists of time series output
HYDADD:	Concantenates two successive time series
SNAPVEC:	Generates vector plots of model output
SNAPLST:	Generates lists of field arrays described in SNAPVEC
RAYPLT:	Generates wave ray plots of RCPWAVE output
PROFPLT:	Generate profile plots of model output
EXIT:	Terminates this CMSPOST session

The user types 'exit' or 'EXIT' to terminate the CMSPOST component. A DISSPLA™ metfil is thus produced. To plot the HYDPLT metfil on a Tektronix or Tektronix emulator, the user types:

```
/u3/h2crp1c0/cmsplot
```

and the plot is displayed, as shown below:

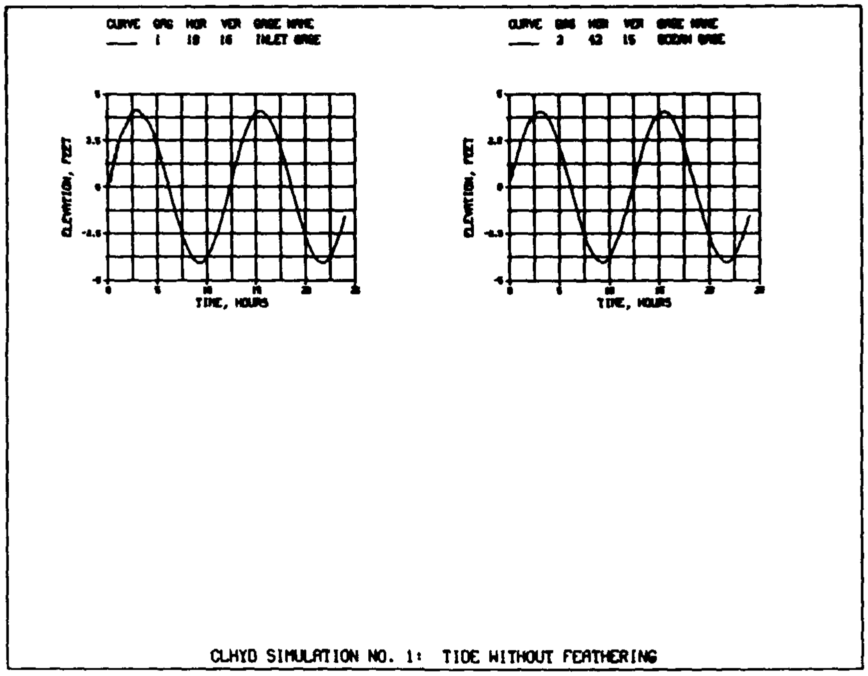
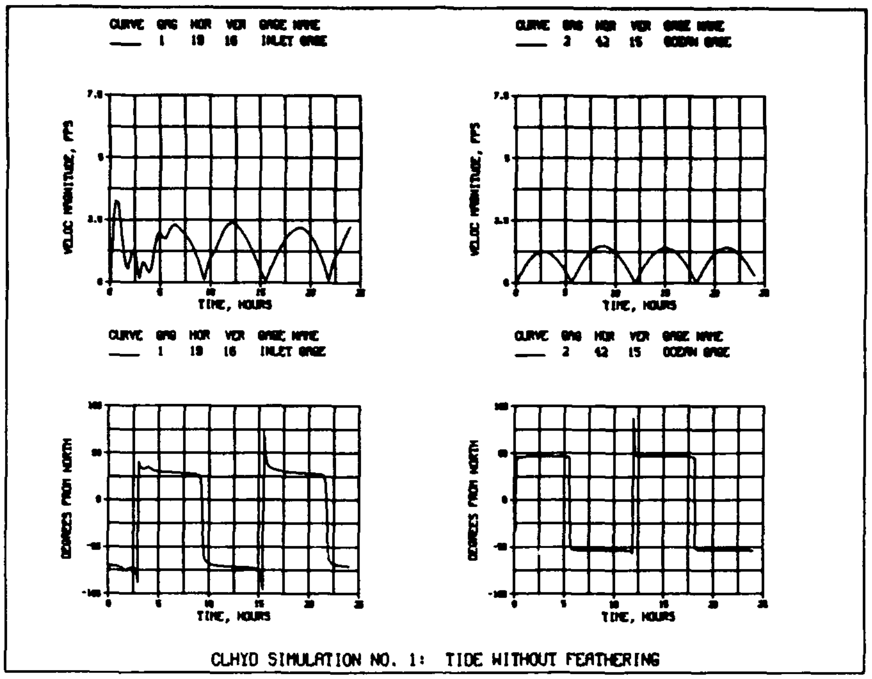


Figure C-1. Sample water surface elevation HYDPLT

Similarly, a time-history of velocity data can be generated using the instruction file below:

```
PFORM 4
TITLE CLHYD SIMULATION NO. 1:  TIDE WITHOUT FEATHERING
VAXIS 6.0 2.0
VGAG1 1-2
```



CLHYD SIMULATION NO. 1: TIDE WITHOUT FEATHERING

Figure C-2. Sample velocity HYDPLT

In the following example, time-histories of wind and pressure for an SPH simulation are displayed. The instruction file for this plot was simply:

```
WGAG1
WAXIS 120 20 2.1
```

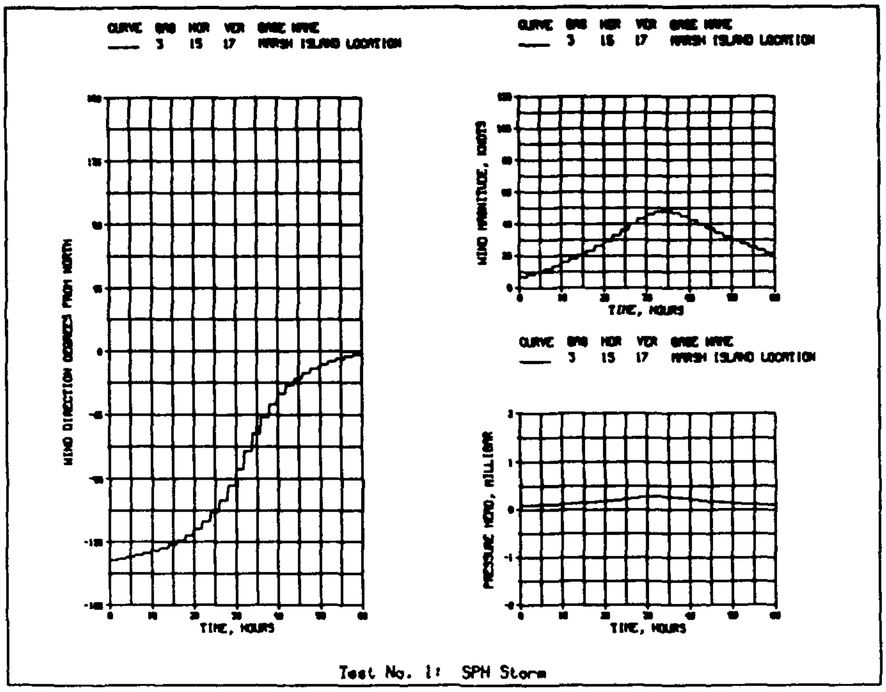


Figure C-3. Sample wind and pressure HYDPLT

Program HYDLST

16. Program HYDLST is a general purpose program for printing gage time-history records generated and stored by the models contained in CMS. The CMS models save the following information for each gage specified by a RECGAGE record: water surface elevations, x and/or y water velocity components, and x and y wind velocity components. Atmospheric pressures are saved if SPH is used to generate the wind fields. Discharges, saved using an XRECRANG or YRECRANG record when running the models, are also stored in this file.

17. A maximum of four time-history data files may be processed simultaneously by program HYDLST, with each data file containing up to 120 gages. No gage can contain more than 1,000 sampling points.

18. An instruction file must be created before execution can begin. Options to change the default formats are included in this file. The following instruction commands, which were described in Table C-2 are valid for this program:

```
TIMES
TGAG_
TADJ_
VGAG_
WGAG_
RGAG_
```

A sample instruction file for program HYDLST is given below:

```
TGAG1 1-2
```

19. To invoke program HYDLST, the user enters the command:

h2crplc1:larry$ /u3/h2crplc0/cms

The CMS responds:

```
          W E L C O M E   T O . . .

     XXXXX        X     X       XXXXX
    X     X       XX   XX      X     X
    X             X X X X      X
    X             X  X  X       XXXXX
    X             X     X            X
    X     X       X     X      X     X
     XXXXX        X     X       XXXXX

             Return for more...
```

```
**********************************************************************
*                          C M S   COMPONENTS                        *
*--------------------------------------------------------------------*
*  Options:                                                          *
*                                                                    *
*  CMSGRID (Maps, plots, and lists the numerical grid)  ------->  1 *
*                                                                    *
*  CMSMODEL (Compiles, links, loads, and executes                    *
*                   numerical models)  ------------------------>  2 *
*                                                                    *
*  CMSPOST (Plots and lists model outputs)  ------------------->  3 *
*                                                                    *
*  CMSUTIL (Additional "utility" programs)  ------------------->  4 *
*                                                                    *
*  Exit CMS  ------------------------------------------------->  e *
**********************************************************************
```

Enter option number ------------------------> 3

The CMS responds:

```
   CCCC       M     M       SSSS      PPPPP       OO       SSSS    TTTTTTT
  C    C      MM   MM      S    S     P    P     O  O     S    S      T
 C            M M M M      S          P    P    O    O    S           T
 C            M  M  M       SSSS      PPPPP     O    O     SSSS       T
 C            M     M           S     P         O    O         S      T
  C    C      M     M      S    S     P          O  O     S    S      T
   CCCC       M     M       SSSS      P           OO       SSSS       T


                            Return for more...
```

```
*********************************************************************
*                                                                   *
*                  USING THE COASTAL MODELING SYSTEM                *
*                                                                   *
*********************************************************************
*                                                                   *
*  Options:                                                         *
*                                                                   *
*    On-Line Help  ------------------------------------------->  1  *
*                                                                   *
*    Enter CMSPOST Module  ----------------------------------->  2  *
*                                                                   *
*    Return to Main Menu  ------------------------------------>  3  *
*                                                                   *
*********************************************************************
```

```
Enter option number  ----------------> 2
```

The CMS responds:

```
                      CMSPOST

 HYDPLT:   Generates plots of time series output
 HYDLST:   Generates lists of time series output
 HYDADD:   Concantenates two successive time series data
SNAPVEC:   Generates vector plots of model output
SNAPLST:   Generates lists of field arrays described
           in SNAPVEC
 RAYPLT:   Generates wave ray plots of RCPWAVE output
PROFPLT:   Generate profile plots of model output
   EXIT:   Terminates this CMSPOST session
```

The user enters: **hydlst**

The CMS responds:

```
H    H  Y     Y  DDDDD    L        SSSSS  TTTTTTT
H    H   Y   Y   D    D   L       S          T
H    H    Y Y    D     D  L       S          T
HHHHHH     Y     D     D  L        SSSS      T
H    H     Y     D     D  L            S     T
H    H     Y     D    D   L            S     T
H    H     Y     DDDDD    LLLLLLL SSSSS      T


                 Return for more. . .
```

Enter the name of the instruction file: **hydlst.ins**

How many input data files will be processed? **5**
the number of files must be between number 1 and 4

Do you want to reenter the number of files to be processed?
Enter yes or no to continue **yes**

Enter the number of files to be processed **1**

Enter the name of the first data set: **hydlst.1**

Enter name of output file **hydlst.out**

The user can choose any meaningful naming convention when selecting filenames.

For example, the user may choose a project name with different extensions for each simulation.

The CMS submits a batch job to the CRAY Y-MP and the system responds:

```
Request 4343.larry submitted to queue:prime
```

```
                          CMSPOST

    HYDPLT:  Generates plots of time series output
    HYDLST:  Generates lists of time series output
    HYDADD:  Concantenates two successive time series
   SNAPVEC:  Generates vector plots of model output
  SNAPLST:  Generates lists of field arrays described
             in SNAPVEC
    RAYPLT:  Generates wave ray plots of RCPWAVE output
  PROFPLT:  Generate profile plots of model output
      EXIT:  Terminates this CMSPOST session
```

The user types 'exit' or 'EXIT' to terminate the CMSPOST component. To list the HYDLST results, the user types:

```
pg hydlst.out
```

The system responds:

FILE 1
FILE TITLE
MOCK-UP TEST
PROVISIONAL STARTING TIME: 0.00
PROVISIONAL ENDING TIME: 0.86E+05
DATA INTERVAL: 360.000
TIME UNIT: SECONDS

ELEVATION LISTING

FILE 1 TITLE: MOCK-UP TEST

FILE 1	GAGE 1	GAGE 2
	X Y	X Y
LOCATION	3 13	11 13
TIME SECONDS	ELEVATION FEET	ELEVATION FEET
0.00	0.500	0.570
360.00	0.500	0.570
720.00	0.500	0.570
	.	
	.	
	.	
10440.00	0.500	0.570
10800.00	0.613	0.570
11160.00	0.900	0.570
11520.00	1.11	0.570
11880.00	1.35	0.629
12240.00	1.49	0.687
12600.00	1.62	0.685
12960.00	1.80	0.724
13320.00	2.02	0.771
13680.00	2.20	0.799
14040.00	2.30	1.03
14400.00	2.42	1.26
14760.00	2.58	1.48
15120.00	2.67	1.72
15480.00	2.86	1.97
15840.00	3.09	2.22
16200.00	3.16	2.47
16560.00	3.17	2.74

Program HYDADD

20. Program HYDADD concatenates two time-history data files from successive simulations of the long-wave models. Program HYDADD is typically applied to a WIFM "cold start" hydrofile and a WIFM "hot start" hydrofile to make one combined hydrofile. No instruction file is required. However, the following requirements must be met:

- a. The two files must be sequential in time.
- b. All gages and ranges must be identical, in number and sequence, in the two files.
- c. Grid rotation must be identical in the two files.

The program will check the above requirements and will terminate with an appropriate error message if any violations are detected.

21. To invoke program HYDADD, the user enters the command:

```
h2crplc1:larry$ /u3/h2crplc0/cms
```

The CMS responds:

```
          W E L C O M E   T O . . .

   XXXXX          X     X        XXXXX
  X     X         XX   XX       X     X
  X               X X X X       X
  X               X  X  X        XXXXX
  X               X     X             X
  X     X         X     X       X     X
   XXXXX          X     X        XXXXX

               Return for more...
```

```
**********************************************************************
*                         C M S   COMPONENTS                         *
*--------------------------------------------------------------------*
*  Options:                                                          *
*                                                                    *
*  CMSGRID (Maps, plots, and lists the numerical grid)  ------->  1 *
*                                                                    *
*  CMSMODEL (Compiles, links, loads, and executes                    *
*                 numerical models)  ------------------------->  2 *
*                                                                    *
*  CMSPOST (Plots and lists model outputs)  ------------------->  3 *
*                                                                    *
*  CMSUTIL (Additional "utility" programs)  ------------------->  4 *
*                                                                    *
*  Exit CMS  ------------------------------------------------->  e *
**********************************************************************
```

```
Enter option number  ------------------------->  3
```

The CMS responds:

```
   CCCC     M     M     SSSS    PPPPP     OO     SSSS   TTTTTTT
  C    C    MM   MM    S    S   P    P   O  O   S    S     T
 C          M M M M    S        P    P  O    O  S          T
 C          M  M  M     SSSS    PPPPP   O    O   SSSS      T
 C          M     M         S   P       O    O       S     T
  C    C    M     M    S    S   P        O  O   S    S     T
   CCCC     M     M     SSSS    P         OO     SSSS      T



                        Return for more...
```

```
**********************************************************************
*                                                                    *
*                USING THE COASTAL MODELING SYSTEM                   *
*                                                                    *
**********************************************************************
*                                                                    *
*  Options:                                                          *
*                                                                    *
*    On-Line Help  --------------------------------------------> 1  *
*                                                                    *
*    Enter CMSPOST Module  ------------------------------------> 2  *
*                                                                    *
*    Return to Main Menu  -------------------------------------> 3  *
*                                                                    *
**********************************************************************
```

Enter option number --------------------> **2**

```
                          CMSPOST

   HYDPLT:  Generates plots of time series output
   HYDLST:  Generates lists of time series output
   HYDADD:  Concatenates two successive time series
  SNAPVEC:  Generates vector plots of model output
  SNAPLST:  Generates lists of field arrays described
            in SNAPVEC
   RAYPLT:  Generates wave ray plots of RCPWAVE output
  PROFPLT:  Generate profile plots of model output
     EXIT:  Terminates this CMSPOST session
```

The user enters: **hydadd**

The CMS responds:

```
H     H    Y     Y    DDDDD        AA      DDDDD       DDDDD
H     H     Y   Y     D    D      A  A     D    D      D    D
H     H      Y Y      D     D    A    A    D     D     D     D
HHHHHH        Y       D     D    AAAAAA    D     D     D     D
H     H       Y       D     D    A    A    D     D     D     D
H     H       Y       D    D     A    A    D    D      D    D
H     H       Y       DDDDD      A    A    DDDDD       DDDDD

                    Return for more. . .
```

Enter the name of the first data set: **file1.hyd**

Enter the name of the second data set: **file2.hyd**

Enter the name of combined data set: **filecom.hyd**

The user can choose any meaningful naming convention when selecting filenames. For example, the user may choose a project name with different extensions for each file.

The CMS submits a batch job to the CRAY Y-MP and the system responds:

Request 4243.larry submitted to queue:prime

The user types 'exit' or 'EXIT' to terminate the CMSPOST component.

The individual files and combined files are as follows:

```
                       MOCK-UP TEST
          11 0.000E+00    1    1    1    0    0
                       SECONDS FEET   FPS      FPS      FEETH20 CFS
       0.00      360.00     720.00   1080.00   1440.00   1800.00   2160.00   2520.00
    2880.00     3240.00    3600.00
 TGAGE     1     3     13GAGE 1           2 13$
      0.500      0.500      0.500     0.500     0.500     0.500     0.500     0.500
      0.500      0.500      0.500
 VGAGE     1     3     13GAGE 1           2 13$
     -0.120     -0.454     -0.218    -0.237    -0.277    -0.276    -0.230    -0.113
     -0.131     -0.194     -0.096
```

```
                          MOCK-UP TEST
        8 0.000E+00    1    1    1    0    0
                      SECONDS FEET    FPS     FPS     FEETH20 CFS
   3600.00   3960.00   4320.00   4680.00   5040.00   5400.00   5760.00   6120.00
TGAGE    1    3   13GAGE 1       2 13$
    01.500     01.500     01.500     01.500     01.500     01.500     01.500
01.500
VGAGE    1    3   13GAGE 1       2 13$
   -1.120    -1.454    -1.218    -1.237    -1.277    -1.276    -1.230    -1.113
```

```
                          MOCK-UP TEST
       18 C.000        1    1    1    0    0
                      SECONDS FEET    FPS    F
      0.00    360.00    720.00   1080.00   1440.00   1800.00   2160.00   2520.00
   2880.00   3240.00   3600.00   3960.00   4320.00   4680.00   5040.00   5400.00
   5760.00   6120.00
TGAGE    1    3   13GAGE 1       2 13$
     0.500     0.500     0.500     0.500     0.500     0.500     0.500     0.500
     0.500     0.500     1.500     1.500     1.500     1.500     1.500     1.500
     1.500     1.500
VGAGE    1    3   13GAGE 1       2 13$
```

Program SNAPVEC

22. Program SNAPVEC produces vector plots of water and wind velocities. A maximum of 100 snapshots can be stored in the data file. An instruction file must be created before execution can begin. Options to change the default plotting formats are included in this file. The following instruction commands, which are described in Table C-3, are valid for this program:

DEBUG	VWINDO_	WWINDO_
NOAVE	VSCALE_	WSCALE_
TIMES	TWINDO_	PWINDO_
TITLE		
GAGLOC		

A sample instruction file for program SNAPVEC is given below:

```
TIMES LAST
WWINDO1  1 26 1 24
WSCALE1 60.0 0.5
```

23. To invoke program SNAPVEC, the user enters the command:

h2crplc1:larry$ **/u3/h2crplc0/cms**

The CMS responds:

```
            W E L C O M E   T O . . .


   XXXXX           X     X          XXXXX
  X     X          XX   XX         X     X
  X                X X X X         X
  X                X  X  X          XXXXX
  X                X     X               X
  X     X          X     X         X     X
   XXXXX           X     X          XXXXX


              Return for more...
```

```
*********************************************************************
*                         C M S   COMPONENTS                        *
*-------------------------------------------------------------------*
*  Options:                                                         *
*                                                                   *
*  CMSGRID (Maps, plots, and lists the numerical grid)  -------> 1 *
*                                                                   *
*  CMSMODEL (Compiles, links, loads, and executes                   *
*                 numerical models)  ------------------------> 2 *
*                                                                   *
*  CMSPOST (Plots and lists model outputs)  ------------------> 3 *
*                                                                   *
*  CMSUTIL (Additional "utility" programs)  ------------------> 4 *
*                                                                   *
*  Exit CMS  -------------------------------------------------> e *
*********************************************************************
```

```
Enter option number  ------------------------>  3
```

The CMS responds:

```
  CCCC     M     M     SSSS    PPPPP      OO      SSSS    TTTTTTT
 C    C    MM   MM    S    S   P    P    O  O    S    S      T
C          M M M M    S        P    P   O    O   S           T
C          M  M  M     SSSS    PPPPP    O    O    SSSS       T
C          M     M         S   P        O    O        S      T
 C    C    M     M    S    S   P         O  O    S    S      T
  CCCC     M     M     SSSS    P          OO      SSSS       T



                       Return for more...
```

```
*********************************************************************
*                                                                   *
*                USING THE COASTAL MODELING SYSTEM                  *
*                                                                   *
*********************************************************************
*                                                                   *
*  Options:                                                         *
*                                                                   *
*    On-Line Help  -------------------------------------------> 1   *
*                                                                   *
*    Enter CMSPOST Module  -----------------------------------> 2   *
*                                                                   *
*    Return to Main Menu  ------------------------------------> 3   *
*                                                                   *
*********************************************************************
```

Enter option number --------------------> 2

The CMS responds:

```
                              CMSPOST

     HYDPLT:  Generates plots of time series output
     HYDLST:  Generates lists of time series output
     HYDADD:  Concantenates two successive time series
    SNAPVEC:  Generates vector plots of model output
    SNAPLST:  Generates lists of field arrays described
              in SNAPVEC
     RAYPLT:  Generates wave ray plots of RCPWAVE output
    PROFPLT:  Generate profile plots of model output
       EXIT:  Terminates this CMSPOST session
```

The user enters: **snapvec**

The system responds:

```
  SSSSS    N     N      AA      PPPPP   V     V   EEEEEE    CCCC
 S         NN    N     A  A     P    P  V     V   E        C
 S         N N   N    A    A    P    P  V     V   E       C
  SSSS     N  N  N   AAAAAAAA   PPPPP   V     V   EEEE    C
      S    N   N N   A      A   P        V   V    E       C
      S    N    NN   A      A   P         V V     E        C
 SSSSS     N     N   A      A   P          V      EEEEEE    CCCC


                       Return for more. . .
```

Enter the name of the instruction file: **snapvec.ins**

Valid user responses are:

TEK40 or tek40 - hydrograph file will be plotted on TEKTRONIX 4014 or VT240 terminal

LASER or laser - if you want laser output here at CERC

Enter device name **laser**

Enter name of input file containing snapshots data that were generated by WIFM, CLHYD, SPH, or other model **wifm.snp**

Enter name of output data set **snapshot.out**

The system responds:

```
  STOP
 CP:0.002s,   Wallclock:0.038s,   0.8%   of   6-CPU
Machine
```

The CMS responds:

```
                    CMSPOST

  HYDPLT:  Generates plots of time series output
  HYDLST:  Generates lists of time series output
  HYDADD:  Concatenates two successive time series
 SNAPVEC:  Generates vector plots of model output
SNAPLST:   Generates lists of field arrays described
           in SNAPVEC
  RAYPLT:  Generates wave ray plots of RCPWAVE output
PROFPLT:   Generate profile plots of model output
    EXIT:  Terminates this CMSPOST session
```

The user types 'exit' or 'EXIT' to terminate the CMSPOST component.

To plot the SNAPVEC file on the laser printer, the user transfers the file to the VAX 3300 using the ftp command (see Chapter 2) and types:

laser std00001.dat

A typical SNAPVEC plot is shown below:

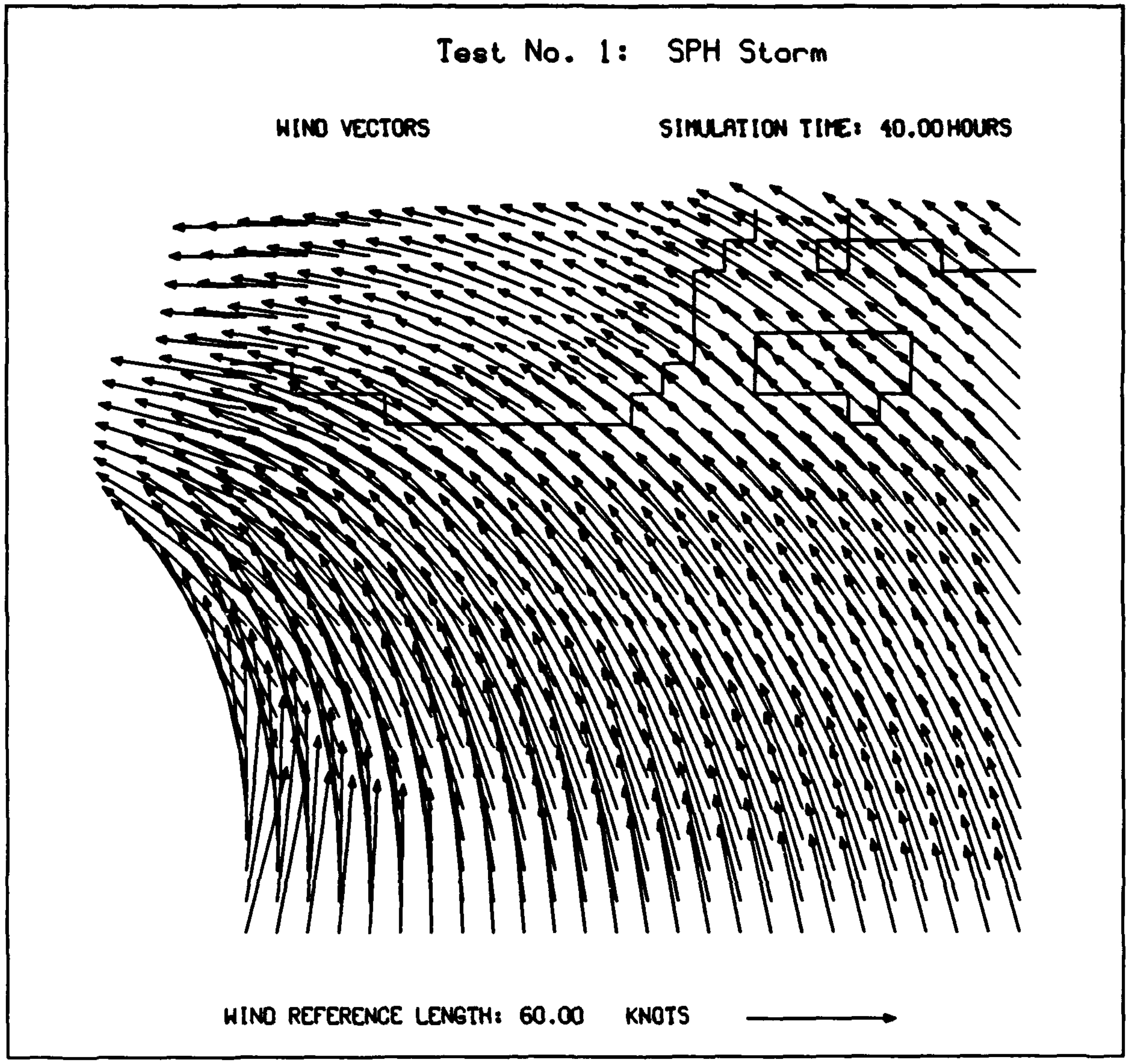


Figure C-4. Sample wind velocity (SNAPVEC) plot

Program SNAPLST

24. Program SNAPLST produces printouts of field array variables. These variables are total water depth, water surface elevation, water velocities, wind velocities, and atmospheric pressure. Water and wind velocities may be printed as x and y components, or as magnitude and direction. Atmospheric pressures are printed if SPH is used, either as a stand-alone model or as a component of WIFM, to generate the wind fields. A maximum of 100 snapshots can be stored in the data file.

25. An instruction file must be created before execution can begin. Options to change the default printing formats are included in this file. The following instructions commands, which are described in Table C-3, are valid for this program:

```
DEBUG     TSAMPL_     VSAMPL_     WSAMPL_     PSAMPL_
TIMES     TFORMT_     VFORMT_     WFORMT_     PFORMT_
                 VPOLAR_     WPOLAR_
```

A sample instruction file for program SNAPLST is given below:

```
TIMES   1
TFORMT1 1 5 1 4
TSAMPL1 1 1
```

26. To invoke program SNAPLST, the user enters the command:

h2crplcl:larry$ **/u3/h2crplc0/cms**

The CMS responds:

```
W E L C O M E   T O . . .


  XXXXX       X     X       XXXXX
 X     X      XX   XX      X     X
 X            X X X X      X
 X            X  X  X       XXXXX
 X            X     X            X
 X     X      X     X      X     X
  XXXXX       X     X       XXXXX


Return for more...
```

```
*******************************************************************
*                          C M S   COMPONENTS                     *
*-----------------------------------------------------------------*
*  Options:                                                       *
*                                                                 *
*  CMSGRID (Maps, plots, and lists the numerical grid)  -------> 1 *
*                                                                 *
*  CMSMODEL (Compiles, links, loads, and executes                 *
*                  numerical models)  ------------------------> 2 *
*                                                                 *
*  CMSPOST (Plots and lists model outputs)  ------------------> 3 *
*                                                                 *
*  CMSUTIL (Additional "utility" programs)  ------------------> 4 *
*                                                                 *
*  Exit CMS  -------------------------------------------------> e *
*******************************************************************
```

Enter option number -----------------------> 3

The CMS responds:

```
  CCCC     M      M     SSSS     PPPPP      OO      SSSS    TTTTTTT
 C    C    MM    MM    S    S    P    P    O  O    S    S      T
C          M M M M     S         P    P   O    O   S           T
C          M  M  M      SSSS     PPPPP    O    O    SSSS       T
C          M     M          S    P        O    O        S      T
 C    C    M     M     S    S    P         O  O    S    S      T
  CCCC     M     M      SSSS     P          OO      SSSS       T


                        Return for more...
```

```
*********************************************************************
*                                                                   *
*                USING THE COASTAL MODELING SYSTEM                  *
*                                                                   *
*********************************************************************
*                                                                   *
*  Options:                                                         *
*                                                                   *
*    On-Line Help ------------------------------------------> 1     *
*                                                                   *
*    Enter CMSPOST Module ----------------------------------> 2     *
*                                                                   *
*    Return to Main Menu -----------------------------------> 3     *
*                                                                   *
*********************************************************************
```

Enter option number ------------------> 2

The CMS responds:

```
                        CMSPOST

   HYDPLT:  Generates lists of time sereis output
   HYDLST:  Generates lists of time series output
   HYDADD:  Concatenates two successive time series
  SNAPVEC:  Generates vector plots of model output
  SNAPLST:  Generates lists of field arrays described
            in SNAPVEC
   RAYPLT:  Generates wave ray plots of RCPWAVE output
  PROFPLT:  Generate profile plots of model output
     EXIT:  Terminates this CMSPOST session
```

The user enters: snaplst

The system responds:

```
 SSSSS   N     N     AA      PPPPP   L         SSSSS  TTTTTTT
S        NN    N    A  A     P    P  L        S          T
S        N N   N   A    A    P    P  L        S          T
 SSSS    N  N  N  AAAAAAAA   PPPPP   L         SSSS      T
     S   N   N N  A      A   P       L             S     T
     S   N    NN  A      A   P       L             S     T
SSSSS    N     N  A      A   P       LLLLLLL  SSSSS      T


                   Return for more. . .
```

Enter the name of the instruction file: snaplst.ins

Enter the name of the input data set: snaplst.1

Enter the name of the output data set snaplst.out

The system responds:

```
   STOP
 CP:002s,   Wallclock:0:105s,   0.3%   of   6-CPU
Machine
```

```
                       CMSPOST

  HYDPLT:  Generates plots of time series output
  HYDLST:  Generates lists of time series output
  HYDADD:  Concatenates two successive time series
 SNAPVEC:  Generates vector plots of model output
 SNAPLST:  Generates lists of field arrays described
           in SNAPVEC
 RAYPLT:   Generates wave ray plots of RCPWAVE output
 PROFPLT:  Generate profile plots of model output
    EXIT:  Terminates this CMSPOST session
```

The user types 'exit' or 'EXIT' to terminate the CMSPOST component.

To display the output file, the user enters:

```
pg snaplat.out
```

and the system responds:

```
1       MOCK_UP TEST
        SURFACE ELEVATIONS                  (FEET     )
        SNAPSHOT TIME -     1hrs    0MIN   0SEC

        X=       1        2        3        4        5
      Y=
        4      7.13     7.25     7.22     7.29     7.44
        3      7.13     7.21     7.20     7.29     7.48
        2      7.13     7.16     7.09     7.13     7.24
        1      7.13     7.13     7.13     7.13     7.13
```

Program RAYPLT

27. Program RAYPLT is a wave ray plotting program specific to model RCPWAVE output only. RCPWAVE saves wave angle data for each grid cell if a PLOTREC record is contained in the RCPWAVE input file. The wave angle information is used to generate a wave ray plot for each wave condition simulated by RCPWAVE.

28. An instruction file must be created and stored before execution can begin. Options to change the default plotting formats are included in this file. The following instruction commands, which are described in Table C-4, are valid for this program:

```
TITLE       RATIO
ROTAN       DEBUG
COAST
DUNIT
XYINC
```

A sample instruction file for program RAYPLT is given below:

```
TITLE DUCK, NC
ROTAN 0
COAST E
DUNIT m
XYINC 12 24
RATIO 1 4
DEBUG
```

29. To invoke program RAYPLT, the user enters the command:

```
h2crplc1:larry$ /u3/h2crplc0/cms
```

Table C-4

Instruction File Commands for Wave Ray Plots

Type	CARDID	Data	Default	Description
[F]	TITLE	title	TITLE1	General plot title. Title size is 64 characters.
[F]	ROTAN		0.0	Rotation angle for north arrow.
[F]	COAST	E, W, or G	none	Selection of east, west, or gulf coast.
[F]	DUNIT	ft or m	ft	Distance units for shoreline data.
[F]	RATIO		none	X and Y increment for calculating wave rays.
[F]	XYING		1 4	Cell spacing in the x and y directions.
[F]	DEBUG		none	Generates output to locate errors in processing.

The CMS responds:

```
          W E L C O M E   T O . . .

   XXXXX          X     X        XXXXX
  X     X         XX   XX       X     X
  X               X X X X       X
  X               X  X  X        XXXXX
  X               X     X             X
  X     X         X     X       X     X
   XXXXX          X     X        XXXXX

             Return for more...
```

```
*********************************************************************
*                          C M S   COMPONENTS                       *
*-------------------------------------------------------------------*
*  Options:                                                         *
*                                                                   *
*  CMSGRID (Maps, plots, and lists the numerical grid) -------> 1 *
*                                                                   *
*  CMSMODEL (Compiles, links, loads, and executes                   *
*                 numerical models) ------------------------> 2 *
*                                                                   *
*  CMSPOST (Plots and lists model outputs) -----------------> 3 *
*                                                                   *
*  CMSUTIL (Additional "utility" programs) -----------------> 4 *
*                                                                   *
*  Exit CMS -------------------------------------------------> e *
*********************************************************************
```

Enter option number ------------------------> 3

The CMS responds:

```
  CCCC      M     M     SSSS     PPPPP      OO      SSSS    TTTTTTT
 C    C     MM   MM    S    S    P    P    O  O    S    S      T
C           M M M M    S         P    P   O    O   S           T
C           M  M  M     SSSS     PPPPP    O    O    SSSS       T
C           M     M         S    P        O    O        S      T
 C    C     M     M    S    S    P         O  O    S    S      T
  CCCC      M     M     SSSS     P          OO      SSSS       T


                        Return for more...
```

```
*********************************************************************
*                                                                   *
*                 USING THE COASTAL MODELING SYSTEM                 *
*                                                                   *
*********************************************************************
*                                                                   *
*  Options:                                                         *
*                                                                   *
*    On-Line Help -------------------------------------------> 1    *
*                                                                   *
*    Enter CMSPOST Module -----------------------------------> 2    *
*                                                                   *
*    Return to Main Menu ------------------------------------> 3    *
*                                                                   *
*********************************************************************
```

Enter option number ------------------> 2

The CMS responds:

```
                         CMSPOST

   HYDPLT:  Generates lists of time sereis output
   HYDLST:  Generates lists of time series output
   HYDADD:  Concatenates two successive time series
  SNAPVEC:  Generates vector plots of model output
  SNAPLST:  Generates lists of field arrays described
            in SNAPVEC
   RAYPLT:  Generates wave ray plots of RCPWAVE output
  PROFPLT:  Generate profile plots of model output
     EXIT:  Terminates this CMSPOST session
```

The user enters: **rayplt**

The system responds:

```
RRRRR        AA       Y     Y    PPPPP    L        TTTTTTT
R    R      A  A       Y   Y     P    P   L           T
R    R     A    A       Y Y      P    P   L           T
RRRRR     AAAAAAAA       Y       PPPPP    L           T
R R       A      A       Y       P        L           T
R  R      A      A       Y       P        L           T
R   R     A      A       Y       P        LLLLLL      T

                    Return for more. . .
```

Enter the name of the instruction file: **rayplt.ins**

Enter the name of the shoreline file: **rayplt.shl**

Enter the name of the wave angle file: **rayplt.ang**

Valid user responses are:

TEK40 or tek40 - (hydrograph file will be plotted on TEKTRONIX 4014 or VT240 terminal)

LASER or laser - (hydrograph file plotted on laser printer)

Enter device name **TEK40**

Enter name of output data file: rayplt.out

The CMS submits a batch job to the CRAY Y-MP and the system responds:

```
   STOP
  CP:002s,   Wallclock:0:105s,   0.3%   of   6-CPU
 Machine
```

```
                    CMSPOST

 HYDPLT:  Generates plots of time series output
 HYDLST:  Generates lists of time series output
 HYDADD:  Concatenates two successive time series
SNAPVEC:  Generates vector plots of model output
SNAPLST:  Generates lists of field arrays described
          in SNAPVEC
 RAYPLT:  Generates wave ray plots of RCPWAVE output
PROFPLT:  Generate profile plots of model output
   EXIT:  Terminates this CMSPOST session
```

The user types 'exit' or 'EXIT' to terminate the CMSPOST component. To plot the RAYPLT metfil on a Tektronix or Tektronix emulator, the user types:

/u3/h2crplc0/cmsplot

and the plots are displayed, as shown below:

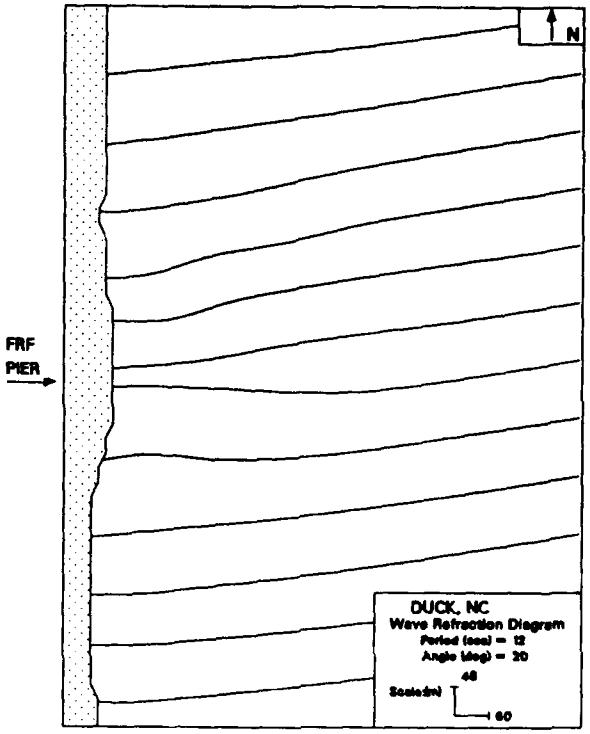


Figure C-5. RAYPLT for Duck, North Carolina, Case 1

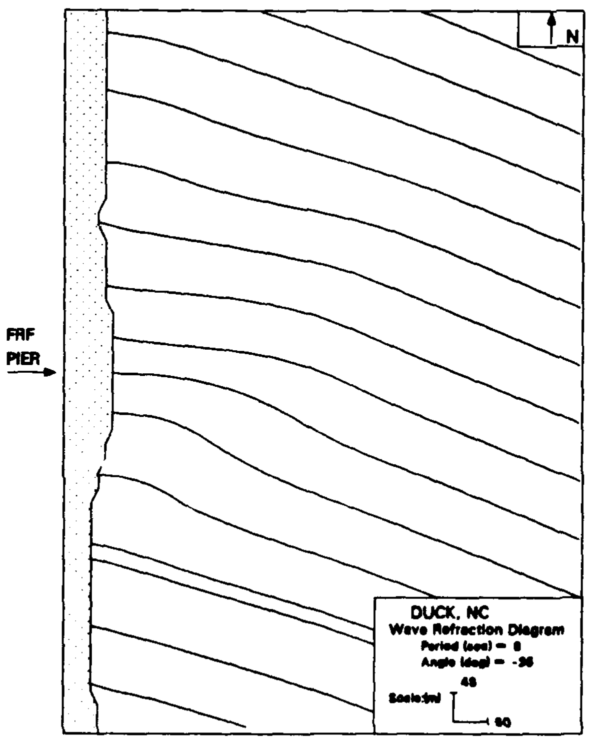


Figure C-6. RAYPLT for Duck, North Carolina, Case 2

Program PROFPLT

30. Program PROFPLT is a general purpose program for generating profile plots of data produced by the models in CMS. Field arrays, such as bathymetry, water surface level, wave height, magnitude of water velocity, and magnitude of wind velocity, can be: (a) saved by the models (using RECSNAPS), or (b) read directly from the model input file (i.e., BATHSPEC) for use by PROFPLT. A one-dimensional "line" from the array is plotted in profile form to show the distribution of the variable along the selected "transect." For example, if a mound exists in a given study area, one could select a transect through the mound, and plot the bathymetry and wave height over the mound.

31. A maximum of 100 profiles can be processed during one PROFPLT session. An instruction file must be created before execution can begin. Options to change the default plotting formats are included in this file. The following instruction commands, which are decribed in Table C-5, are valid for this program:

```
DEBUG
TITLE
YAXIS
TRANS
LINE_
BATHY
CURV2
TIMES
```

A sample instruction file for program PROFPLT is given below:

```
TRANS 1
LINE1 1 20 27 27
BATHY
YAXIS DEPTH, meters
DEBUG
TITLE PROFPLT EXAMPLE
```

Table C-4

Instruction File Commands for Wave Ray Plots

Type	CARDID	Data	Default	Description
[F]	TITLE	title	TITLE1	General plot title. Title size is 64 characters.
[S]	TRANS	integer		Number of transects to be plotted.
[S]	LINE_	X1 X2 Y1 Y2	none	Select command to process transects. Qualifier _ referenced to transect number. The number of LINE records corresponds to the number specified on TRANS. X1 = minimum x-direction cell number to plot X2 = maximum x-direction cell number to plot Y1 = minimum y-direction cell number to plot Y2 = maximum y-direction cell number to plot Note that X1 must equal X2 for a Y transect and Y1 must equal Y2 for a X transect.
[S]	BATHY			Plot bathymetry for all transects.
[S]	CURV2			Secondary variable plotted for all transects.
[F]	TIMES	TMIN TMAX TINC		Specify time plotting limits and increment. Default values are calculated from the data set.

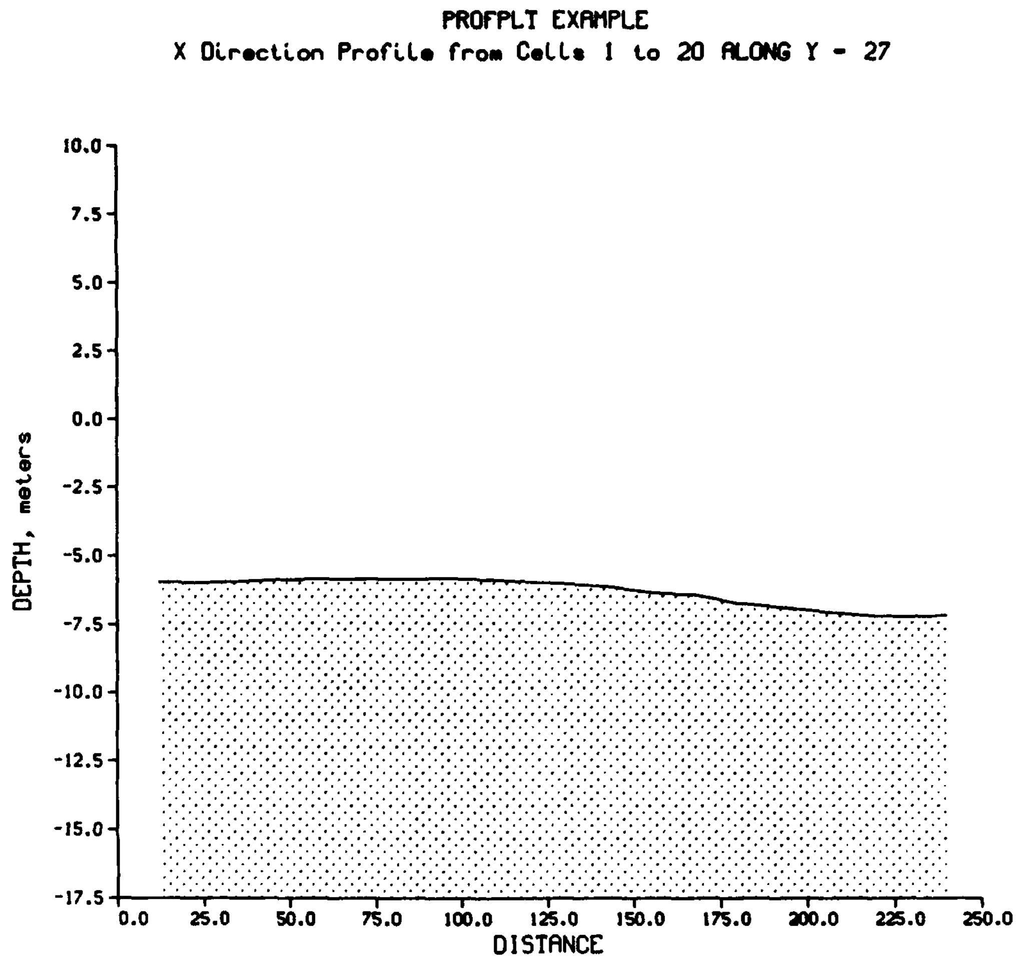


Figure C-7. Sample PROFPLT bathymetric plot

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